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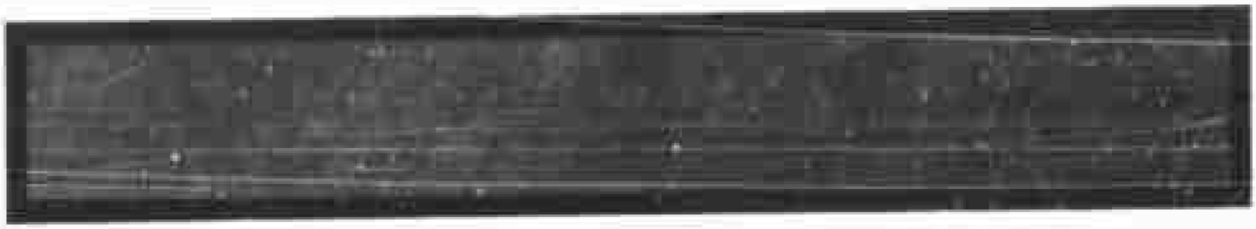

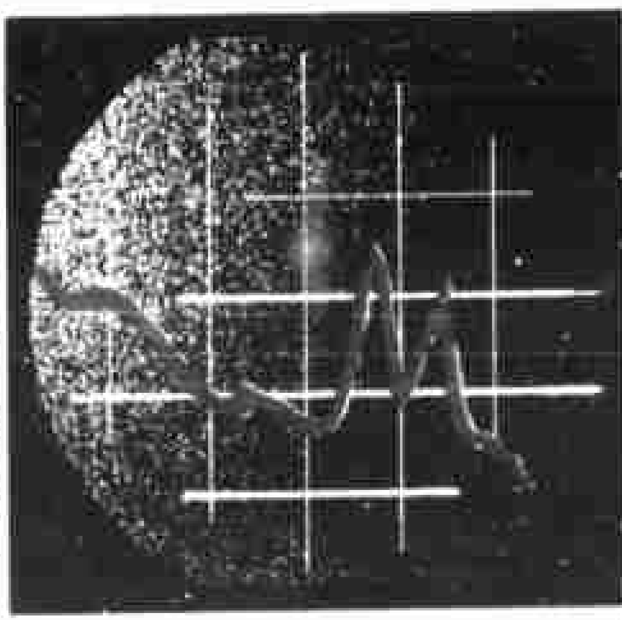

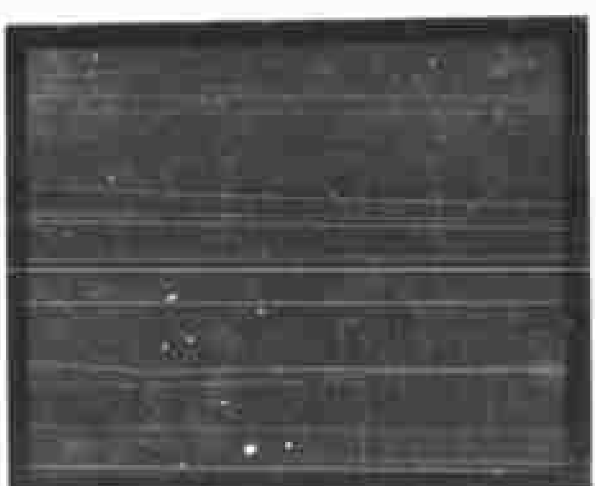

ACTIVATION ANALYSIS RESEARCH LABORATORY

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GAMMA-RAY SPECTRA and SENSITIVITIES for 14 MeV NEUTRON ACTIVATION ANALYSIS

M. CUYPERS and J. CUYPERS

6 GAMMA RAY SPECTRA AND SENSITIVITIES

For

14 MEV NEUTRON ACTIVATION ANALYSIS,

~~By~~

10 M. Cuypers
J. Cuypers

11 12 Apr[redacted]66

12 275p.

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SUMMARY TABLE OF DETECTION LIMITS FOR 14 m.e.v. NEUTRON ACTIVATION ANALYSIS

NEUTRON FLUX = 2×10^8 $n/cm^2/sec.$

ELEMENT	RADIOISOTOPE PRODUCED	HALF LIFE	GAMMA RAY ENERGY (m.e.v.)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT (mg)
Aluminum	Mg^{27}	9.5 m	0.84	5 m	1 m	5 m	1145	0.14
	Mg^{27}	9.5 m	1.01	5 m	1 m	5 m	364	0.35
	Na^{24}	15 h	1.37	5 m	1 m	5 m	18	5.1
	Na^{24}	15 h	2.75	5 m	1 m	5 m	9	4.3
Antimony	Sb^{120}	15.9 m	0.51	5 m	1 m	5 m	950	0.17
Arsenic	Ge^{75m}	49 s	0.14	2.4 m	49 S	2.4 m	45	4.6
Barium	Ba^{137m}	2.6 m	0.662	5 m	1 m	5 m	5209	0.09
Boron	Be^{11}	13.6 s	2.12	40.8 s	13.6 s	40.8 s	29	
Bromine	Br^{79m}	4.8 s	0.21	15 s	5 s	15 s	106	1.0
	Br^{78}	6.5 m	0.51	5 m	1 m	5 m	3327	0.05
	Br^{78}	6.5 m	0.62	5 m	1 m	5 m	310	0.50
Cadmium	Cd^{111m}	49 m	0.15	5 m	: m	5 m	107	1.2
	Cd^{111m}	49 m	0.25	5 m	1 m	5 m	363	0.39
Cerium	Ce^{139m}	55 s	0.74	2.75 m	55 s	2.75 m	1320	0.11
Cesium	Cs^{132}	6.58d	0.67	5 m	1 m	5 m	13	8.5
Chlorine	Cl^{34m}	32 m	0.14	5 m	1 m	5 m	30	4.1
	Cl^{34m}	32 m	0.51	5 m	1 m	5 m	8	21

SUMMARY TABLE (Cont'd.)

ELEMENT	RADIOISOTOPE PRODUCED	HALF LIFE	GAMMA RAY ENERGY (m.e.v.)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT (mg)
Chromium	V^{52}	3.77 m	1.43	5 m	1 m	5 m	710	0.21
Cobalt	Mn^{56}	2.58 h	0.845	5 m	1 m	5 m	28	4.3
	Co^{58}	71 d	0.81					
Copper	Cu^{62}	9.9 m	0.51	5 m	1 m	5 m	3273	0.05
Dysprosium	Dy x-ray		0.05	3.75 m	75 s	3.75 m	1390	0.10
	Dy^{165m}	75.4 s	0.108	3.75 m	75 s	3.75 m	388	0.25
Fluorine	O^{19}	29 s	0.20	1.5 m	29 s	1.5 m	375	0.96
	O^{19}	29 s	0.20	5 m	1 m	5 m	266	1.4
	F^{18}	110 m	0.51	5 m	1 m	5 m	340	0.68
	N^{16}	7.35 s	6.13	22 s	7.3 s	22 s	38	
Erbium	Er^{167m}	2.5 s	0.208	7.5 s	2.5 s	7.5 s	8	4 - 1.7
Europium	Eu^{152m}	96 m	0.09	5 m	1 m	5 m	32	2.9
	Pm^{150}	2.7 h	0.33	5 m	1 m	5 m	6	18.0
Gadolinium	Gd^{161}	3.7 m	0.36	5 m	1 m	5 m	12	14
	Gd^{159}	18 h						
Gallium	Ga^{68}	68 m	0.51	5 m	1 m	5 m	917	0.18

SUMMARY TABLE (Cont'd.)

ELEMENT	RADIOISOTOPE PRODUCED	HALF LIFE	GAMMA RAY ENERGY (m.e.v.)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT (mg)
Germanium	Ge^{75m}	49 s	0.14	2.4 m	49 s	2.4 m	198	0.38
	Ge^{75m}	49 s	0.14	5 m	1 m	5 m	294	0.46
	Ge^{75}	82 m	0.27	5 m	1 m	5 m	34	3.4
	Ga^{74}	8 m	0.60	5 m	1 m	5 m	34	5.8
Gold	Au^{196}	6.2 d	0.356 + 0.331	5 m	1 m	5 m	16	7.0
	Au^{196}	6.2 d	0.43	5 m	1 m	5 m	7	19
	Au^{197m}	7.2 s	0.279	21.6 s	7.2 s	21.6 s	60	0.60
Hafnium	Hf^{179m}	19 s	0.217	57 s	19 s	57 s	171	1.0
	Yb^{176m}	12 s	0.29	57 s	19 s	57 s	20	6.9
Indium	In^{116m}	54 m	0.137	5 m	1 m	5 m	71	2.0
	In^{116m}	54 m	0.406	5 m	1 m	5 m	250	0.30
	In^{116m}	54 m	1.08	5 m	1 m	5 m	240	1.41
	In^{116m}	54 m	1.27	5 m	1 m	5 m	252	0.40
Iron	Mn^{56}	2.58 h	0.845	5 m	1 m	5 m	86	1.3
Iridium	Ir x-ray		0.065	15 s	4.9 s	15 s	5	14
	Ir x-ray	3.2 h	0.063	5 m	1 m	5 m	15	10
	Ir^{191m}	4.9 s	0.129	15 s	4.9 s	15 s	2	18

SUMMARY TABLE (Cont'd.)

ELEMENT	RADIOISOTOPE PRODUCED	HALF LIFE	GAMMA RAY ENERGY (m.e.v.)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT (mg)
Lead	Pb x-ray		0.075	18.3 s	6.1 s	18.3 s	0.4	49 - 25
	Pb^{203m}	6.1 s	0.83	18.3 s	6.1 s	18.3 s	1	22 - 12
	Pb^{207m}	0.8 s	0.57	2.4 s	0.8 s	2.4 s	5	7.8 - 3.5
	Pb^{207m}	0.8 s	1.06	2.4 s	0.8 s	2.4 s	3	7.5 - 5.0
	Pb x-ray		0.075	5 m	1 m	5 m	1.8	132
	Pb^{203}	52 h	0.28	5 m	1 m	5 m	0.5	217
Lutetium	Lu x-ray		0.055	5 m	1 m	5 m	13	7.5
	Lu^{176m}	3.7 h	0.088	5 m	1 m	5 m	5	14.5
Magnesium	Ne^{23}	38 s	0.44					
	Mg^{23}	12 s	0.44	1.9 m	38 s	1.9 s	39	4.5
	Na^{25}	60 s	0.40					
	Mg^{23}	12 s	0.44					
	Ne^{23}	38 s	0.44	36 s	12 s	36 s	15	3.4
	Na^{25}	60 s	0.98	3 m	1 m	3 m	16	8.3
	Na^{25}	60 s	0.58	3 m	1 m	3 m	10	15
	Na^{24}	15 h	1.37	3 m	1 m	3 m	12	10
	Na^{24}	15 h	1.37	5 m	1 m	5 m	33	3.6

SUMMARY TABLE (Cont'd.)

ELEMENT	RADIOISOTOPE PRODUCED	HALF LIFE	GAMMA RAY ENERGY (m.e.v.)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT (mg)
Manganese	Mn^{56}	2.56 h	0.84	5 m	1 m	5 m	208	3.8
	V^{52}	3.77 m	1.43	5 m	1 m	5 m	35	0.49
Mercury	Hg x-ray		0.075	5 m	1 m	5 m	224	0.43
	Hg^{199m}	44 m	0.158	5 m	1 m	5 m	210	0.46
		40 m	0.24	5 m	1 m	5 m	38	2.5
	Hg^{199m}	44 m	0.37	5 m	1 m	5 m	30	3.8
Molybdenum	Mo^{91}	15.5 m	0.51	5 m	1 m	5 m	161	1.0
Neodymium	Ce^{139m}	55 s	0.76	3 m	1 m	3 m	375	0.32
	Nd^{141m}	64 s	0.74					
Niobium	Y^{90m}	3.2 h	0.20	5 m	1 m	5 m	7	18
Nickel	Ni^{57}	36 h	0.51	5 m	1 m	5 m	320	0.52
Nitrogen	N^{13}	9.96 m	0.51	5 m	1 m	5 m	350	0.47
Oxygen	N^{16}	7.3 s	6.13	22 s	7.3 s	22 s	91	
Palladium	Pd^{109m}	4.8 m	0.18					
	Ru^{107}	4.2 m	0.19	1.2 m	22 s	1.2 m	308	0.54
	Pd^{107m}	22 s	0.22					
	Pd^{109m}	4.8 m	0.18	5 m	1 m	5 m	732	0.40
	Ru^{107}	4.2 m	0.19					

SUMMARY TABLE (Cont'd.)

ELEMENT	RADIOISOTOPE PRODUCED	HALF LIFE	GAMMA RAY ENERGY (m.e.v.)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT (mg)
Praseodymium	Pr^{140}	3.4 m	0.51	5 m	1 m	5 m	5400	0.03
Phosphorus	P^{30}	2.5 m	0.51	5 m	1 m	5 m	179	0.92
	Al^{28}	2.3 m	1.78	5 m	1 m	5 m	1360	0.04
Potassium	K^{38}	7.7 m	0.51	5 m	1 m	5 m	48	3.4
Rubidium	Rb^{84m}	20 m	0.46	3 m	1 m	3 m	458	0.33
	Rb^{86m}	1 m	0.56	3 m	1 m	3 m	490	0.29
	Rb^{84m}	20 m	0.22 + 0.24	5 m	1 m	5 m	2000	0.11
	Rb^{84m}	20 m	0.46	5 m	1 m	5 m	1490	0.12
	Rb^{86m}	1 m	0.56	5 m	1 m	5 m	635	0.21
Ruthenium	Tc^{101}	14 m						
	Tc^{104}	18 m	0.31 + 0.34	5 m	1 m	5 m	77	1.4
	Ru^{95}	99 m						
Samarium	$Nd^{141m}+Sm^{143m}$	64s+1m	0.75	3 m	1 m	3 m	43	2.3
	$Nd^{141m}+Sm^{143m}$	64s+1m	0.75	5 m	1 m	5 m	51	2.2
	Sm^{143}	9 m	0.51	5 m	1 m	5 m	80	2.1
Selenium	Se^{77m}	18 s	0.16	57 s	19 s	57 s	261	0.44
	Se^{77m}	18 s	0.16	5 m	1 m	5 m	56	1.7
	$Se^{79m}+Se^{81m}$	3.9m+57m	0.10	5 m	1 m	5 m	496	0.24

SUMMARY TABLE (Cont'd.)

ELEMENT	RADIOISOTOPE PRODUCED	HALF LIFE	GAMMA RAY ENERGY (m.e.v.)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT (mg)
Silicon	Al^{28}	2.30 m	1.78	5 m	1 m	5 m	2360	0.07
Silver	Ag^{109m}	40 s	0.088	2.2 m	44 s	2.2 m	146	2.2
	Ag^{107m}	44 s	0.093					
	Ag x-ray		0.021	2.2 m	44 s	2.2 m	316	0.40
	Ag^{106}	24 m	0.51	5 m	1 m	5 m	2127	0.08
Sodium	Ne^{23}	38 s	0.44	1.9 m	38 s	1.9 m	200	0.37
	Ne^{23}	38 s	0.44	33 s	11 s	33 s	75	0.50
	F^{20}	11 s	1.63	33 s	11 s	33 s	93	0.25
Strontium	Sr^{85m}	70 m	0.23	5 m	1 m	5 m	63	1.8
	Sr^{87m}	2.8 h	0.39	5 m	1 m	5 m	198	0.80
Tantalum	Ta x-ray		0.06	5 m	1 m	5 m	165	0.48
Terbium	Te x-ray		0.044	33 s	11 s	33 s	123	0.93
Tin	Sn^{123}	40 m	0.153	5 m	1 m	5 m	173	0.69
Titanium	Se^{46m}	20 s	0.14	1 m	20 s	1 m	17	2.5
	Se^{46m}	20 s	0.14	5 m	1 m	5 m	7	18
	Se^{50}	1.8 m	0.52	5 m	1 m	5 m	9	18
	Se^{49}	57.5 m	1.76	5 m	1 m	5 m	8	7.1

SUMMARY TABLE (Cont'd.)

ELEMENT	RADIOISOTOPE PRODUCED	HALF LIFE	GAMMA RAY ENERGY (m.e.v.)	T_{act}	T_{dec}	T_{cnt}	COUNTS/Mg/T_{cnt}	DETECTION LIMIT (mg)
Tungsten	W x-ray		0.059	15.9 s	5.3 s	15.9 s	29	3.0 - 1.3
	W^{183m}	5.3 s	0.11	15.9 s	5.3 s	15.9 s	2.5	15 - 8.0
	W^{185m}	1.7 m	0.13					
	W^{183m}	5.3 s	0.16	15.9 s	5.3 s	15.9 s	2	27 - 13
	W x-ray		0.059	5 m	1 m	5 m	38	4.2
	W^{185m}	1.7 m	0.175	5 m	1 m	5 m	15	9.3
	W^{185m}	1.7 m	0.13	5 m	1 m	5 m	12	15
Vanadium	Ti^{51}	5.8 m	0.32	5 m	1 m	5 m	1150	0.14
	V^{52}	3.77 m	1.43	5 m	1 m	5 m	144	0.70
Yttrium	Y^{89m}	16 s	0.91	48 s	16 s	48 s	314	0.58
Zinc	Zn^{63}	38 m	0.51	5 m	1 m	5 m	212	0.77
Zirconium	Zr^{89m}	4.2 m	0.59	48 s	16 s	48 s	32	2.9
	Zr^{89m}	4.2 m	0.59	5 m	1 m	5 m	645	0 25
	Y^{89m}	16 s	0.91	48 s	16 s	48 s	15	2.9

II. INTRODUCTION

INTRODUCTION

In recent years, the small Cockcroft-Walton and Van de Graaff accelerators, producing 14 Mev neutrons, have become more than a research tool. In many laboratories, these neutron generators are used to perform a large number of routine analyses based on 14 Mev neutron activation. The number of elements determined, however, has been somewhat limited. The technique of 14 Mev neutron activation has often been chosen because of its speed and in some cases for its sensitivities which may be between 50 μg and 1000 μg for most of the elements.

In order to predict the sensitivity for the determination of an element, several compilations have been published. Gillepsie and Hill[1] published a compilation of detection limits, for the different elements, based on theoretical calculations of the minimum amount of element required to produce 100 dpm. Kusaka et al[2] have compiled the gamma-ray spectra for 39 elements. However, the detection limits have not been calculated in that work.

Since the detection limit of a radioisotope depends on the region of the spectrum in which its emitted gamma ray is located, owing to differences in background at different energies, the ultimate sensitivity or detection limit should be evaluated as a function of the background.

The present study has been conducted mainly to determine experimentally the detection limits for elements under specified experimental conditions. This work has been instigated by the fact that the limits published by several authors for several elements have very often been found to be unrealistic for analytical purposes.

Two main factors have dictated the experimental conditions reported in this catalogue. The first is that the number of analyses to be performed is large. This means that the irradiation and counting time is limited. For long irradiation times (20 min.) it is suggested that reference be made to the work of Aude and Laverlochere[3].

The second factor is that the highest sensitivity must be reached. For this reason, optimum conditions for irradiation, decay and counting time have been chosen. Also two 3" x 3" NaI(Tl) cryatals were used to enhance the detection efficiency. The experimental data has not been taken at maximum output of the neutron generator, because of the limited life time of the tritium targets. These results can, however, easily be extrapolated for a higher flux.

Most attention has been given to the analytically useful photopeaks in the gamma-ray spectrum. For a more complete study of all the radioisotopes formed with 14 Mev neutron

activation and the evaluation of the cross sections for the nuclear reactions, reference should be made to the work of Strain and Ross[4].

This catalogue is intended to serve as a basis to enable the experimenter to evaluate the type of spectrum and the activity to be expected from a particular element and from the matrix in which it is present. From this indication, the feasibility of an analysis can be evaluated.

EXPERIMENTAL ARRANGEMENTS

(1) Neutron Source: A 150 kv Cockcroft-Walton accelerator (Texas Nuclear Corporation) was used. The neutron flux was obtained by bombarding a target of tritiated zirconium (diameter 3.2 cm) with a deuteron beam of 100 - 500μA. The $H_1^3(H_1^2,n_0^1)He_2^4$ reaction produced the 14 Mev neutrons used to irradiate the different elements. A thin tritium target holder was designed and the back of the tritium target was cooled with water.

(2) Sample Transfer System: Figure 1 shows the irradiation, transfer and counting system used. The samples were introduced at the counting station in a polyethylene pneumatic tube and transferred to the irradiation station using a vacuum cleaner. The distance between these two stations was approximately 28 m. When the sample passed in front of the photo-

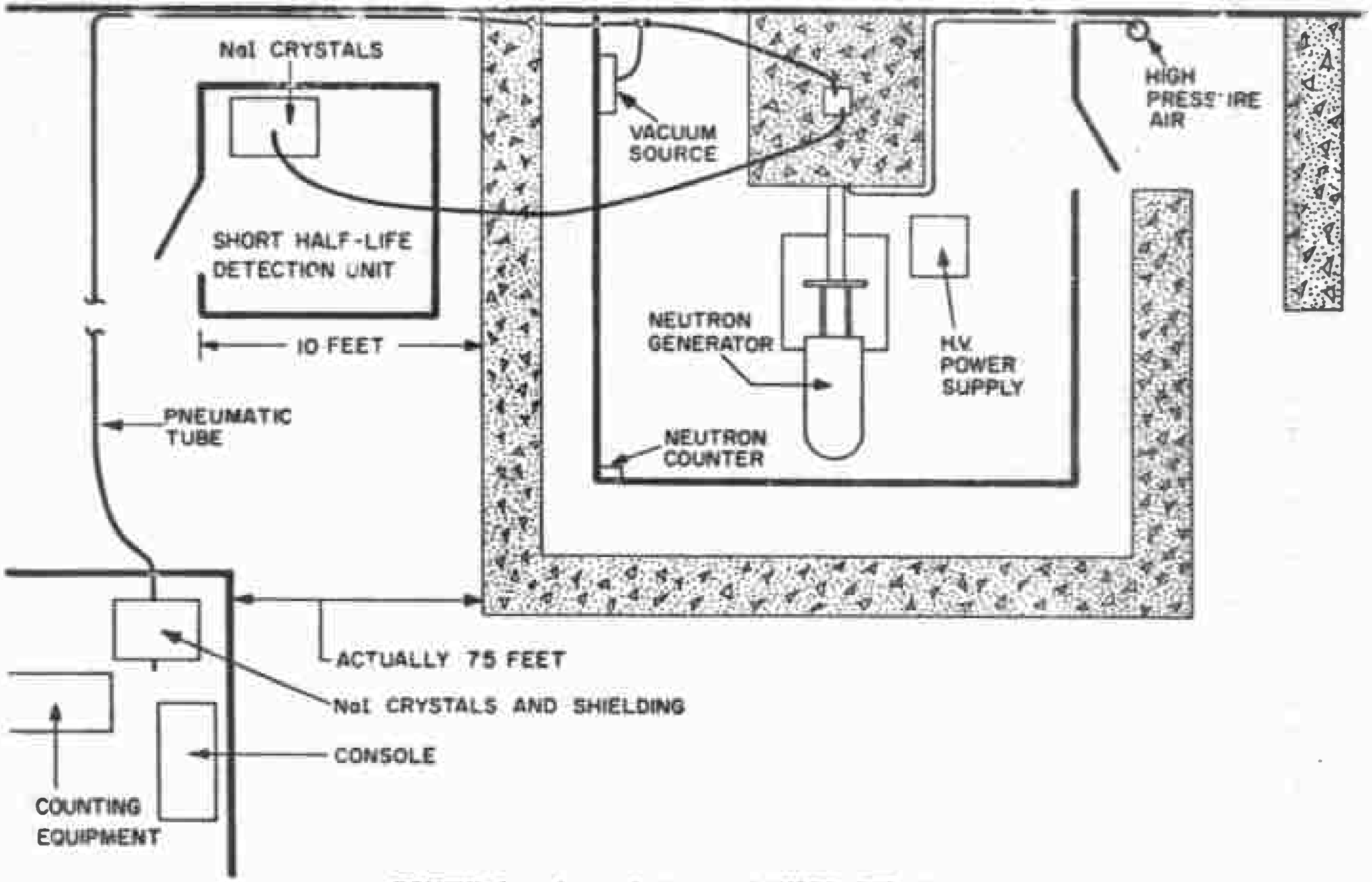


FIGURE 1. ACTIVATION ANALYSIS SYSTEM

electric cell located close to the target, the production of neutrons started. The pneumatic tube was positioned against the back of the target holder, so that the distance from the middle of the sample container to the target was 1.65 cm.

After a preset irradiation time, the beam was automatically switched off and the sample was transferred back to the counting station using compressed air (140 lbs/in^2). The average transfer time of the sample was 4 seconds.

To study the radioisotopes with half lives shorter than 5 seconds, a different pneumatic system was used. In this case, the distance between the irradiation and the counting station was only 6.75 m, and the transfer path was virtually linear. The average transfer time in this system was 100 milliseconds.

(3) Counting Equipment: (a) Gamma-ray detectors. The gamma-rays from the radioisotopes produced were detected by two matched 3" x 3" NaI(Tl) crystals (Harshaw). After transfer from the irradiation station, the sample was positioned between the two crystals which were 2.4 cm apart.

Between each crystal and the sample, a sheet of lucite 0.75 cm thick was interposed to limit the interference of β^- radiation.

The detectors were connected to a 400-channel pulse

height analyzer (RIDL). The resolution of the detectors for the 0.662 Mev photopeak of Cs^{137} was 9.0%.

(b) Neutron detectors. Two neutron detection systems were used: (1) A $B^{10}F_3$ counter (N. Wood G10-5) enveloped in 4 cm of paraffine and located at 4.25 m from the target was connected to a counting scaler and gave the relative flux integrated over the irradiation time. (2) An ionization chamber (Anton type 813) enveloped in 4 cm of paraffine was located inside of the accelerator shielding (65 cm from the target). The latter neutron detector is connected to a micromicroammeter (Keithley), and enabled an average relative flux reading to be obtained at any time during irradiation.

(4) Shielding: The tritium target of the accelerator was located in the middle of a concrete castle. The distance from the target to the concrete was never less than 30 cm, in order to keep the thermal neutron production as low as possible. The thickness of the concrete wall was 57 cm.

The accelerator and its immediate shielding were located in a room constructed with 58 cm thick concrete walls.

The gamma-ray detectors were surrounded by a lead castle lined with a graded shield of cadmium and copper. The dimension

of the castle is 60 cm x 82 cm x 53 cm and the thickness of the lead is 5.2 cm.

EXPERIMENTAL PROCEDURES

(1) Sample Preparation: The samples were all packed in cylindrical polyethylene vials (2.4 cm long, 0.8 cm inner diameter with an 0.125 cm wall thickness) which were heat-sealed.

The samples were irradiated either in the elemental form, as in the case of the metals, or in the form of oxides, nitrates, or sulfates. On each spectrum given in the second part of this catalogue, the composition of the irradiated element is given.

(2) Irradiation, Decay And Counting Time: The radioisotopes formed after irradiation of the different elements in the flux of 14 Mev neutrons may be classified in two groups:

(a) radioisotopes with a half life shorter than one minute
(b) radioisotopes with a half life longer than one minute

Activation time - three half lives of the particular radioisotope under consideration. This irradiation time provided approximately 86% of the activity at saturation. For longer irradiation times, the rate of increase of the induced activity becomes smaller.

<u>Waiting time</u> - one half life of the produced radioisotopes. The highest sensitivity would have been obtained by counting the sample as soon as possible after irradiation. The imposed waiting time of one half life permitted the determination of the sensitivities of the different elements under equivalent conditions from the point of view of the nuclear properties.

<u>Counting time</u> - three half lives of the produced radioisotopes. An increase in total count of only 7% would have been obtained by counting for four half lives. In addition the probability of accumulating more noise than signal becomes greater.

For the second group of radioisotopes, those with half lives longer than one minute, the activation time was standardized to five minutes, waiting time to one minute, and counting time to five minutes. These somewhat arbitrarly chosen conditions may be justified for the following reasons:

(a) The tritium targets possess a limited life time. Much longer irradiation times are not practical since the number of samples which can be irradiated with one target becomes smaller. In addition the time of analysis becomes prohibitively long if a large number of samples have to be run.

(b) One minute waiting time permits the decay of the shorter lived radioisotopes.

It should be noted that if more than one isotope was obtained by irradiating a particular element, the above procedure was carried out for each radioisotope.

(3) <u>Neutron Flux Measurement</u>: The scaler reading on the $B^{10}F_3$ counter was related to the specific activity of copper discs taped against the target and thus to the neutron flux, using the Texas Convention criteria. These criteria were devised and defined in April, 1965 at the Second Conference on "Modern Trends in Activation Analysis". A complete description of the Texas Convention is given in Appendix I.

Under the irradiation conditions used, the ratio of specific activity obtained from the small copper discs (diameter 1 cm) to that from the large discs (diameter 5 cm) is 0.52.

In the second part of this work, the flux (T.C.) calculated using the small copper disc taped against the target is given on each spectrum. This size of disc was chosen because the vial has a height comparable to the diameter of the small disc.

Knowing the absolute number of counts at 0.51 Mev obtained from Cu^{62} following the Texas Convention, the absolute neutron dose (F) was easily determined for a particular disc.

Instead of calculating the activity for a decay time of one minute, this was calculated for a decay time equal to zero. The obtained value is divided by the area of the disc giving the activity/cm^2/min (A). The flux F is then calculated from equation (1).

$$F = \frac{A}{\sigma\ n\ k\ (1-e^{-0.693t/T}) \times 60} \quad . . . . . . (1)$$

where

σ = cross section for the $Cu^{63}(n,2n)Cu^{62}$ reaction = 0.55 barns

n = number of atoms/cm^2 = $\frac{6.02 \times 10^{23} \times w}{63.5}$

(w being the number of grams of copper per cm^2 in the copper disc)

k = isotopic abundance of Cu^{63} = 0.69

t = irradiation time = 1 min

T = half life of Cu^{62} = 9.9 min

The factor $\frac{1}{\sigma\ n\ k\ (1-e^{-0.693t/T}) \times 60} = 2 \times 10^2$

in these conditions:

The flux, F, obtained here, even when calculated from a disc of area 0.785 cm^2, can be considered as very close to the absolute neutron flux (n/sec/cm^2).

All the irradiations were performed with fluxes (T.C.) between 3.9×10^6 to 8.6×10^6 c/min/gm Cu, measured against

the tritium target holder, corresponding to an absolute neutron dose of 2.9×10^8 to 6.5×10^8 n/sec/cm^2. A four times higher flux could have been obtained easily with the 14 Mev neutron generator. The life time of the target in these conditions, however, was reduced by half.

RESULTS

(1) Calculation of Activity Under Photopeak: The area under the photopeaks was determined by drawing the base line across the bottom of the peak, and summing the counts between the photopeak and this base line.

A computer program was written by D. W. Berry to calculate the photopeak areas and normalize the data to the same neutron flux conditions.

No attempt has been made to make an absolute photopeak area determination using the method of Heath[5], but the base line has always been determined using the same criteria being finally very close to that obtained with the method of Heath.

(2) Normalization Of The Data: To compare the spectra obtained from the different elements, a normalization of the data was necessary.

(a) All the photopeak counts were normalized to a neutron scaler reading equivalent to 200,000 counts/min corresponding to a flux (T.C.) of 5.3×10^6 counts/min/gm Cu or

an absolute neutron dose of 4.0 x 10^8 n/sec/cm^2 against the tritium target. This is a normalization to the neutron output of the accelerator.

(b) Because it was found that reproducible positioning of the samples relative to the target was difficult, each time the accelerator was moved, a second normalization appeared to be necessary. Every day four solutions of copper nitrate, each containing 128 mg of copper, were irradiated for one minute and counted for one minute, after a one minute decay time. The percent standard deviation for these four copper solutions was 4 to 5%. No variation in activity during a one-day period was observed. All the photopeak counts of the different elements were normalized to a copper solution photopeak activity of 13,000 counts/min.

This last procedure is thus a normalization for neutron dose on the sample. The following equation expresses both these normalizations:

$$A_n = \frac{A_r \times F_n \times t_{act}}{F_r} \times \frac{Cu_n}{Cu_r} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (2)$$

where

A_n = normalized photopeak counts

A_r = experimentally obtained photopeak counts

F_n = Normalized neutron scaler reading (2 x 10^5 counts/min)

F_r = experimental neutron scaler reading

t_{act} = activation time

Cu_n = normalized copper solution activity (13,000 counts/min)

Cu_r = experimentally obtained activity for copper solution

(3) Calculation Of The Sensitivities: To estimate the sensitivity of determination of an element using a particular gamma-ray peak in the spectrum, decreasing amounts of the element were irradiated under similar conditions. After normalization of the activities a calibration curve expressing the photopeak activity as a function of the weight in mg was drawn. The slope of this curve gave the number of photopeak counts per milligram of the element. The intercept with the activation axis also provided the information on the residual photopeak activity due to trace elements in the vial and the effect of background activity.

This last point is of great importance especially when the sensitivity of an element producing a 0.51 Mev photopeak has to be determined. An empty polyethylene vial indeed produced, after irradiation, an activity at 0.51 Mev which decayed with a half life of 10 minutes. This was probably due to N^{13} which can be produced by collision of 14 Mev neutrons with hydrogen atoms in the vial. These high energy protons interact with the carbon of the vial and give the $C^{13}(p,n)N^{13}$ reaction.

(4) Calculation Of The Detection Limits: The limit of sensitivity for the detection of a photopeak in a spectrum is highly dependent upon the region of the spectrum in which the photopeak is located and the matrix activity in that region. From 0 to 0.25 Mev, the natural background activity in the spectrum is much greater than in higher energy regions. To express this limit of sensitivity of an element, taking into consideration these facts, the following calculations were made:

(a) The total counts in the photopeak region were summed.

(b) The background in the photopeak region was determined using the base line method.

(c) The value of three times the square root of the counts in this background were calculated. (Three time the standard deviation)

(d) The limit of sensitivity was considered to have been reached when the photopeak counts equals to three sigma of the background count.

The justification for using this three sigma criterion is as follows: With 99% confidence, the number of counts due to background lies within the range bounded by the estimated means value plus or minus three times the calculated standard deviation of the mean value.

In practice it is more realistic to say that when the photopeak counts equal a value of six sigma of the background, a semi-quantitative analysis can be performed. For the three

sigma criterion the matrix activity has to be known very accurately, leaving even then some doubt about the presence of the element looked for.

METHOD OF PRESENTATION OF FINAL RESULTS

In the second part of this work, elements are presented and their behavior in a 14 Mev Neutron flux is explained. The elements are discussed in alphabetical order. Four tables are given for each element.

Table I - This table lists all the nuclear reactions which can be obtained from the element studied. Only (n,p), (n,α), (n,2n) and (n,n') reactions have been considered. In a few cases (n,γ), (n,n'p) and (n,n'α) reactions were observed. The compilation of this nuclear data has been made using the "Chart of Nuclides"[6] (Knolls Atomic Power Laboratory).

Table II - This table explains the experimentally obtained photopeaks given in the figure supplied for each element. Optimum irradiation, waiting and counting conditions have been chosen to produce the different nuclear reactions. When no detectable activity was observed, it has been noted in a remark following Table II. In a few cases the energies observed in the spectrum did not correspond to the energies given in the "Chart of Nuclides". It was often referred to data in ref (5) and (7).

Every time a photopeak was observed, a decay curve was made to check its origin. On each figure, the activation, waiting and counting times are given together with the composition of the compound irradiated and the flux (Texas Convention). All the spectra have been normalized to the activity produced by 1 gram of the element studied.

Table III - This table shows the sensitivities for the determination of the element based on the evaluation of the slope of the calibration curves of the photopeak area at a certain peak. The irradiation, waiting and counting conditions are given and the sensitivity is expressed in counts/milligram of the studied element during count time. The detection limit has been calculated as previously explained in the "RESULTS" section.

Table IV - This last table contains the observed interfering nuclear reactions for the photopeaks on which sensitivity calculations were based.

An interfering nuclear reaction is defined as:

(1) One which produces the same radioisotope as is produced by the studied element, or

(2) One which produces a radioisotope omitting gamma photons of the same energy and also having approximately the same half-life as the radioisotope produced by the studied element.

ELEMENTS PRODUCING NO DETECTABLE GAMMA-RAY ACTIVITY

For a certain number of elements, either no characteristic peaks were observed, or the activity for 300 milligrams of the element was too low to perform a good quantitative analysis.

In general, only the activity due to the vial was observed. The investigated elements are: calcium, bismuth, sulphur, holmium, thulium.

REMARKS

(1) Several elements having a high cross section for thermal neutrons produce an appreciable activity when irradiated in the 14 Mev neutrons flux. A thermalization of the neutrons can always be expected due to the low Z element present in the vial, pneumatic tube, sample itself and cooling water.

The reactions observed are listed in Table I.

(2) Only one (n,n'p) and one (n,n'α) reaction was observed in this study: $Zr^{90}(n,n'p)Y^{89m}$, $Nb^{93}(n,n'\alpha)Y^{89m}$.

(3) The activity due to an empty vial gives no photopeaks in the spectrum. The half life of the produced radioisotope is 10 minutes and has been assigned to Nitrogen-13. Figure 2 shows a typical gamma-ray spectrum of an empty vial. The activity at an energy of 0.51 Mev for 5 minutes activation time, one minute waiting time and 5 minutes counting time

Table I

Observed (n,γ) Reactions

Nuclear Reactions	Gamma Ray Energy (Mev)	Nuclear Reactions	Gamma Ray Energy (Mev)
$Al^{27}(n,\gamma)Al^{28}$	1.78	$Dy^{164}(n,\gamma)Dy^{165m}$	0.108, 0.51, 0.36, 0.15
$Mn^{55}(n,\gamma)Mn^{56}$	0.84	$In^{115}(n,\gamma)In^{116m}$	0.406, 0.137, 1.08, 1.27 0.81, 1.49, 1.77
$V^{51}(n,\gamma)V^{52}$	1.43	$Gd^{160}(n,\gamma)Gd^{161}$	0.044, 0.102, 0.165, 0.18 0.316, 0.363
$Sn^{122}(n,\gamma)Sn^{123}$	0.16	$Co^{59}(n,\gamma)Co^{60m}$	1.33

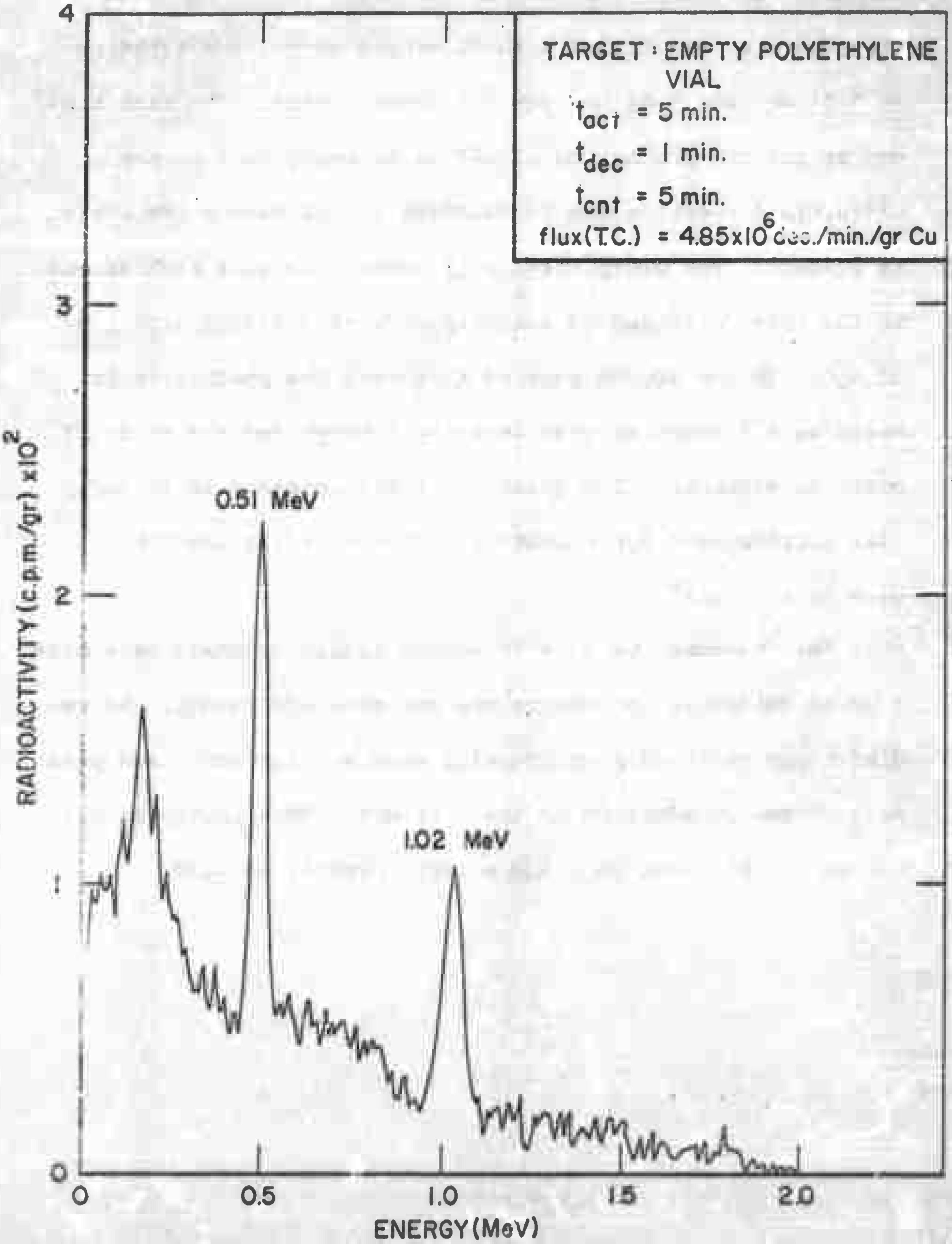

TARGET : EMPTY POLYETHYLENE VIAL
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) = 4.85×10^6 dec./min./gr Cu
0.51 MeV
1.02 MeV
RADIOACTIVITY (c.p.m./gr) $\times 10^2$
ENERGY (MeV)
0
1
2
3
4
0
0.5
1.0
1.5
2.0

FIGURE 2

corresponds to 780 counts in our standard flux conditions. When the vial was filled with deionized water, the activity at 0.51 Mev and 1.02 Mev was 3.5 times higher. The same theory as for the production of N^{13} in an empty vial by the $C^{13}(p,n)N^{13}$ reaction can be extended to the case where oxygen is present. The $O^{16}(p,\alpha)N^{13}$ will contribute to a high extent to the total nitrogen-13 activity in a vial filled with 1 ml of H_2O. In the second part of this work the photopeaks labeled as N^{13} refer to vial activity (except for the study of nitrogen element). The quantity of N^{13} obtained in an empty vial corresponded approximately to the activity found by Gilmore and Hull[8].

(4) Because two 3" x 3" sodium iodide crystals have been used as detectors to enhance the counting efficiency, the radioisotope emitting positron will show a coincidence sum peak at 1.02 Mev in addition to the 0.51 Mev. This photopeak will not be visible when only one NaI(Tl) crystal is used.

III. SPECTRA AND SENSITIVITY TABLES

ALUMINUM

TABLE I-Al

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Al^{27}	100%	$Al^{27}(n,p)Mg^{27}$	9.5 m	0.84, 1.01
		$Al^{27}(n,\alpha)Na^{24m}$	0.02 s	IT 0.47
		$Al^{27}(n,\alpha)Na^{24}$	15.00 h	2.75, 1.37
		$Al^{27}(n,2n)Al^{26m}$	6.5 s	$\beta+$
		$Al^{27}(n,2n)Al^{26}$	7.4×10^5 y	1.83, 1.12, $\beta+$

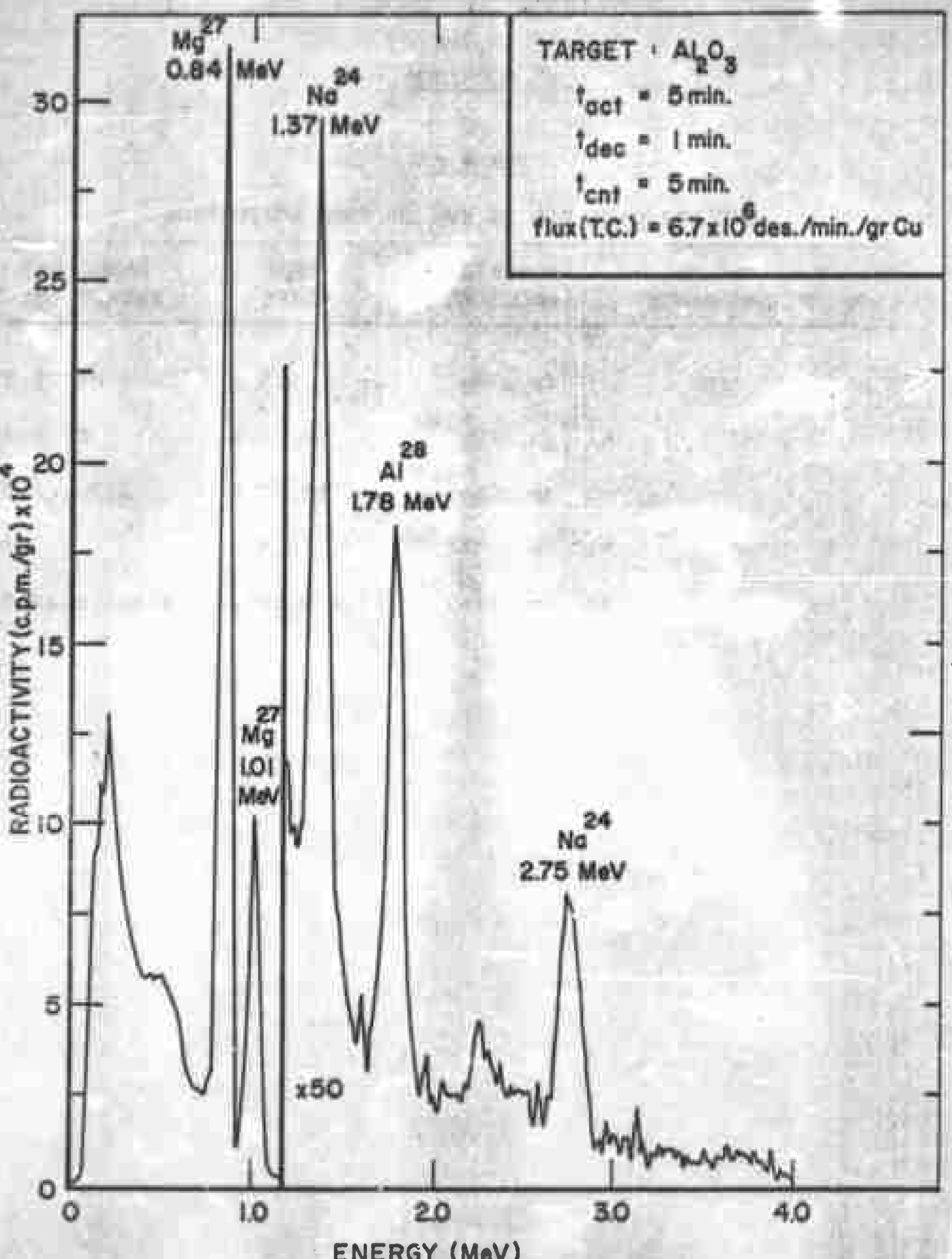

TARGET : Al_2O_3
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) = 6.7×10^6 des./min./gr Cu
Mg^{27} 0.84 MeV
Na^{24} 1.37 MeV
Al^{28} 1.78 MeV
Mg^{27} 1.01 MeV
Na^{24} 2.75 MeV
x50
RADIOACTIVITY (c.p.m./gr) x10^4
0
5
10
15
20
25
30
0
1.0
2.0
3.0
4.0
ENERGY (MeV)

FIGURE I-A1

TABLE II-Al

PEAKS OBSERVED IN FIGURE I-Al

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Al	0.84	$Al^{27}(n,p)Mg^{27}$	9.5 m	
	1.01	$Al^{27}(n,p)Mg^{27}$	9.5 m	
	1.37	$Al^{27}(n,\alpha)Na^{24}$	15 h	
	1.78	$Al^{27}(n,\gamma)Al^{28}$	2.3 m	
	2.75	$Al^{27}(n,\alpha)Na^{24}$	15 h	

NOTE: Al^{26m} ($T_{\frac{1}{2}}$= 6.5s) not detected for 19.5 sec irradiation, 6.5 sec decay and 19.5 sec counting time.

TABLE III-Al

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.84	5 m	1 m	5 m	1145	0.14
1.01	5 m	1 m	5 m	364	0.35
1.37	5 m	1 m	5 m	18	5.1
2.75	5 m	1 m	5 m	9	4.3

ALUMINUM

TABLE IV-Al

POSSIBLE INTERFERING REACTIONS

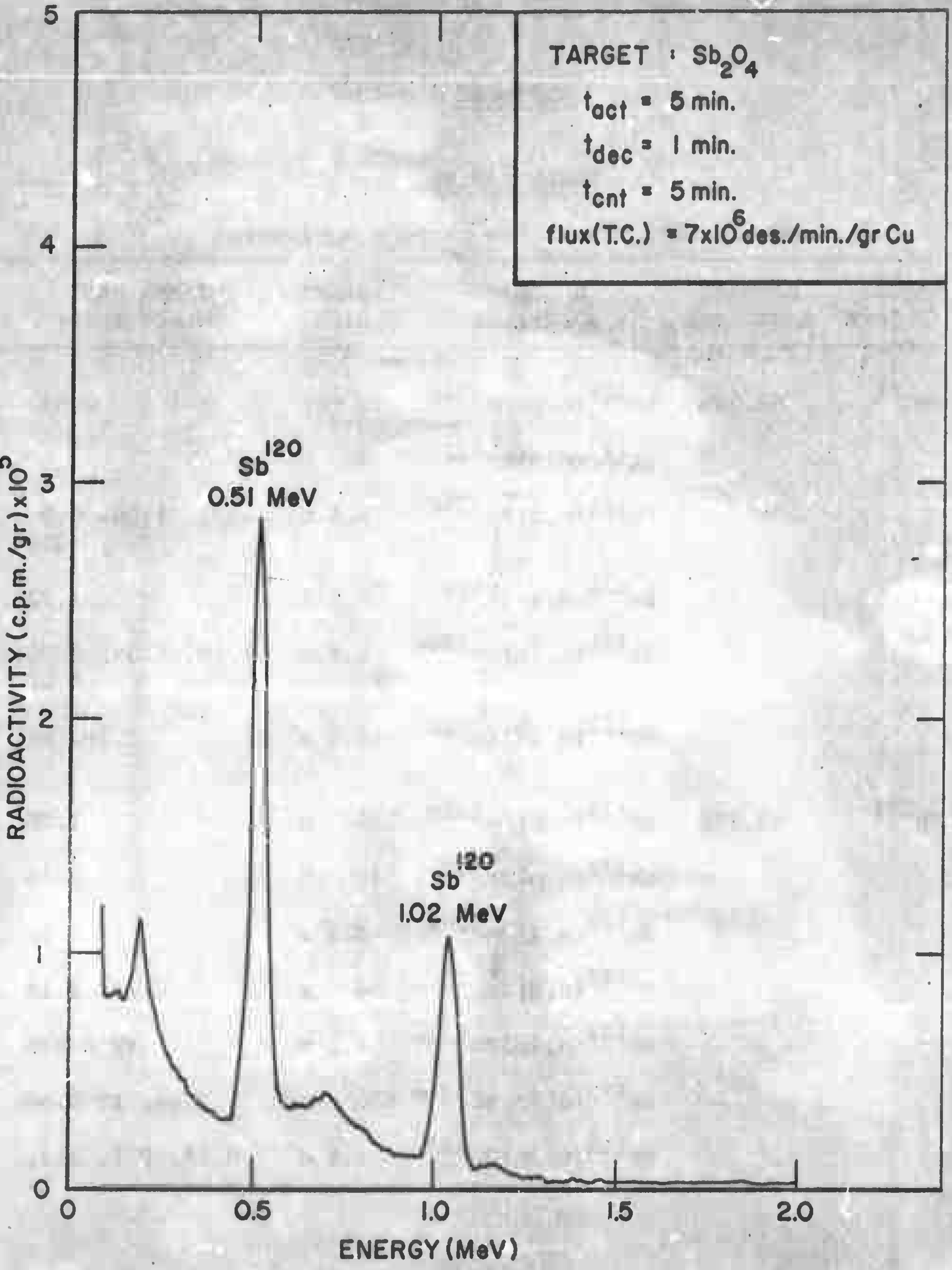
GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.84	Silicon	$Si^{30}(n,\alpha)Mg^{27}$	very low
1.01	Silicon	$Si^{30}(n,\alpha)Mg^{27}$	very low
1.37	Magnesium	$Mg^{24}(n,p)Na^{24}$	
2.75	Magnesium	$Mg^{24}(n,p)Na^{24}$	

ANTIMONY

TABLE I - Sb

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Sb^{121}	57.25%	$Sb^{121}(n,p)Sn^{121m}$	25 y	0.037
		$Sb^{121}(n,p)Sn^{121}$	27 h	
		$Sb^{121}(n,\alpha)In^{118m}$	4.4 m	1.22, 1.05, 0.2, 2.0
		$Sb^{121}(n,\alpha)In^{118}$	5.1 s	1.22
		$Sb^{121}(n,2n)Sb^{120m}$	5.8 d	1.18, 1.03, 0.20, 0.09
		$Sb^{121}(n,2n)Sb^{120}$	15.9 m	1.18, $\beta+$
Sb^{123}	42.75%	$Sb^{123}(n,p)Sn^{123m}$	125 d	1.08
		$Sb^{123}(n,p)Sn^{123}$	40 m	0.16
		$Sb^{123}(n,\alpha)In^{120m}$	3.2 s	1.18
		$Sb^{123}(n,\alpha)In^{120}$	44 s	0.73, 1.18
		$Sb^{123}(n,2n)Sb^{122m}$	4.1 m	IT 0.026
		$Sb^{123}(n,2n)Sb^{122m}$	530 μs	0.06, IT 0.08
		$Sb^{123}(n,2n)Sb^{122}$	2.8 d	0.56, 0.7, 1.1, $\beta+$



TARGET : Sb_2O_4
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) = 7×10^6 des./min./gr Cu
Sb^{120}
0.51 MeV
Sb^{120}
1.02 MeV
RADIOACTIVITY (c.p.m./gr) $\times 10^5$
ENERGY (MeV)
0
0.5
1.0
1.5
2.0
1
2
3
4
5

FIGURE I-Sb

TABLE II-Sb

PEAKS OBSERVED IN FIGURE I-Sb

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Sb	0.51	$Sb^{121}(n,2n)Sb^{120}$	15.9 m	
	1.02	$Sb^{121}(n,2n)Sb^{120}$	15.9 m	0.51 Mev coincidence sum peak

NOTE: In^{118} ($T_{½}$ = 5.1 sec) and In^{120m} ($T_{½}$ = 3.2 sec) not detected for 15 sec irradiation, 5 sec decay and 15 sec counting time.

TABLE III-Sb

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.51	5 m	1 m	5 m	950	0.17

TABLE IV-Sb

POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for antimony from any other element.

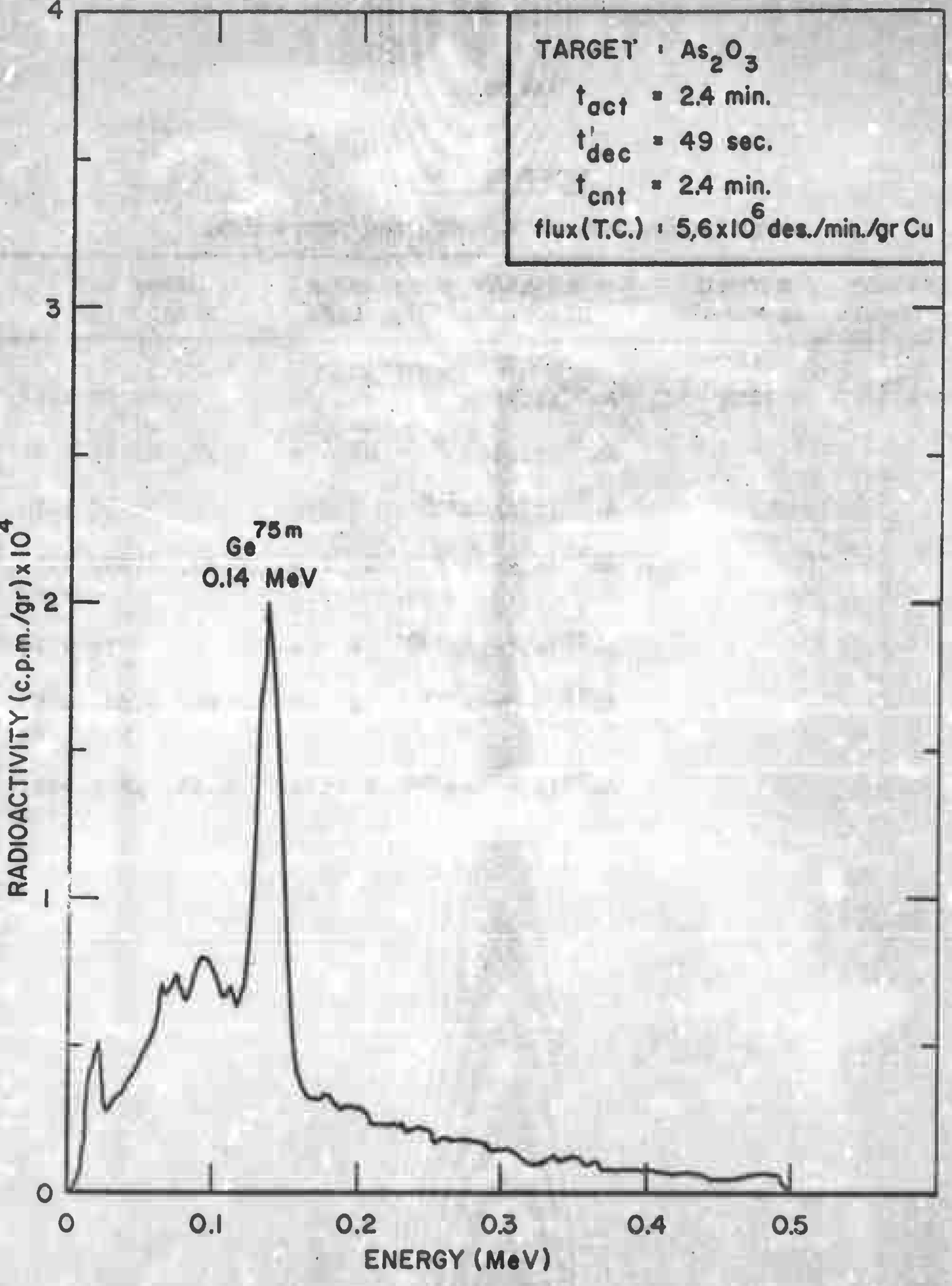
For other positron emitting radioisotopes than Sb^{120} see Section I, Appendix II.

ARSENIC

TABLE I - As

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
As^{75}	100%	$As^{75}(n,p)Ge^{75m}$	49 s	IT 0.14
		$As^{75}(n,p)Ge^{75}$	82 m	0.27, 0.07, 0.63
		$As^{75}(n,\alpha)Ga^{72m}$	0.04s	IT 0.10
		$As^{75}(n,\alpha)Ga^{72}$	14.1 h	0.84, 0.69, 0.11, 2.82
		$As^{75}(n,2n)As^{74m}$	8 s	IT 0.28
		$As^{75}(n,2n)As^{74}$	18 d	0.60, 0.64, 2.53, $\beta+$
		$As^{75}(n,n')As^{75m}$	0.017s	0.28, IT 0.025, 0.305



TARGET : As_2O_3
t_{act} = 2.4 min.
t'_{dec} = 49 sec.
t_{cnt} = 2.4 min.
flux(T.C.) : 5,6x10^6 des./min./gr Cu
Ge^{75m}
0.14 MeV
RADIOACTIVITY (c.p.m./gr) x 10^4
ENERGY (MeV)
0
1
2
3
4
0.1
0.2
0.3
0.4
0.5

FIGURE I-As

TABLE II-As

PEAKS OBSERVED IN FIGURE I-As

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-As	0.14	$As^{75}(n,p)Ge^{75m}$	49 s	

NOTE: As^{74m} ($T_{½}$ = 8 sec) not detected for 24 sec irradiation, 8 sec decay and 24 sec counting time. No other radioisotope detectable in a 5 min irradiation.

TABLE III-As

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.14	2.4 m	49 s	2.4 m	45	4.6

TABLE IV-As

POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.14	Germanium	$Ge^{76}(n,2n)Ge^{75m}$	

BARIUM

TABLE I - Ba

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Ba^{130}	0.101%	$Ba^{130}(n,p)Cs^{130}$	30 m	β+
		$Ba^{130}(n,\alpha)Xe^{127m}$ ↓	75 s	0.125, IT 0.175
		$Ba^{130}(n,\alpha)Xe^{127}$	36.4 d	0.20, 0.17, 0.15, 0.06
		$Ba^{130}(n,2n)Ba^{129m}$ ↓	2.13h	0.182
		$Ba^{130}(n,2n)Ba^{129}$	2.2 h	0.21, 0.22, β+
Ba^{132}	0.097%	$Ba^{132}(n,p)Cs^{132}$	6.58d	0.67, 0.46, 0.51, 2.0; β+
		$Ba^{132}(n,\alpha)Xe^{129m}$	8 d	0.040, IT 0.196
		$Ba^{132}(n,2n)Ba^{131m}$ ↓	14.6 m	0.107, IT 0.078
		$Ba^{132}(n,2n)Ba^{131}$	11.6 d	0.50, 0.122, 0.216, 0.055, 1.03
Ba^{134}	2.42%	$Ba^{134}(n,p)Cs^{134m}$ ↓	2.9 h	0.010, IT 0.13, 0.14
		$Ba^{134}(n,p)Cs^{134}$	2.1 y	0.60, 0.80, 0.20, 1.37
		$Ba^{134}(n,\alpha)Xe^{131m}$	12 d	IT 0.164
		$Ba^{134}(n,2n)Ba^{133m}$ ↓	39 h	0.012, IT 0.276
		$Ba^{134}(n,2n)Ba^{133}$	7.2 y	0.081, 0.36, 0.30, 0.08, 0.38

TABLE I - Ba (Cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Ba^{135}	6.59%	$Ba^{135}(n,p)Cs^{135m}$	53 m	0.78, IT 0.84
		$Ba^{135}(n,p)Cs^{135}$	2.0×10^{6}y	
		$Ba^{135}(n,n')Ba^{135m}$	29 h	IT 0.268
		$Ba^{135}(n,n')Ba^{135m}$	0.33s	~0.7, ~0.8
Ba^{136}	7.81%	$Ba^{136}(n,p)Cs^{136}$	13 d	1.04, 0.83, 0.065, 2.5
		$Ba^{136}(n,\alpha)Xe^{133m}$	2.3 d	IT 0.233
		$Ba^{136}(n,\alpha)Xe^{133}$	5.27d	0.081
		$Ba^{136}(n,2n)Ba^{135m}$	29 h	IT 0.268
		$Ba^{136}(n,2n)Ba^{135m}$	0.33s	~0.7, ~0.8
Ba^{137}	11.32%	$Ba^{137}(n,p)Cs^{137}$	30 y	0.662
		$Ba^{137}(n,n')Ba^{137m}$	2.6 m	IT 0.662
Ba^{138}	71.66%	$Ba^{138}(n,p)Cs^{138}$	32.2 m	1.43, 1.0, 0.46, 2.2, 0.11, 3.3
		$Ba^{138}(n,\alpha)Xe^{135m}$	16 m	IT 0.53
		$Ba^{138}(n,\alpha)Xe^{135}$	9.2 h	0.25, 0.61
		$Ba^{138}(n,2n)Ba^{137m}$	2.6 m	IT 0.662

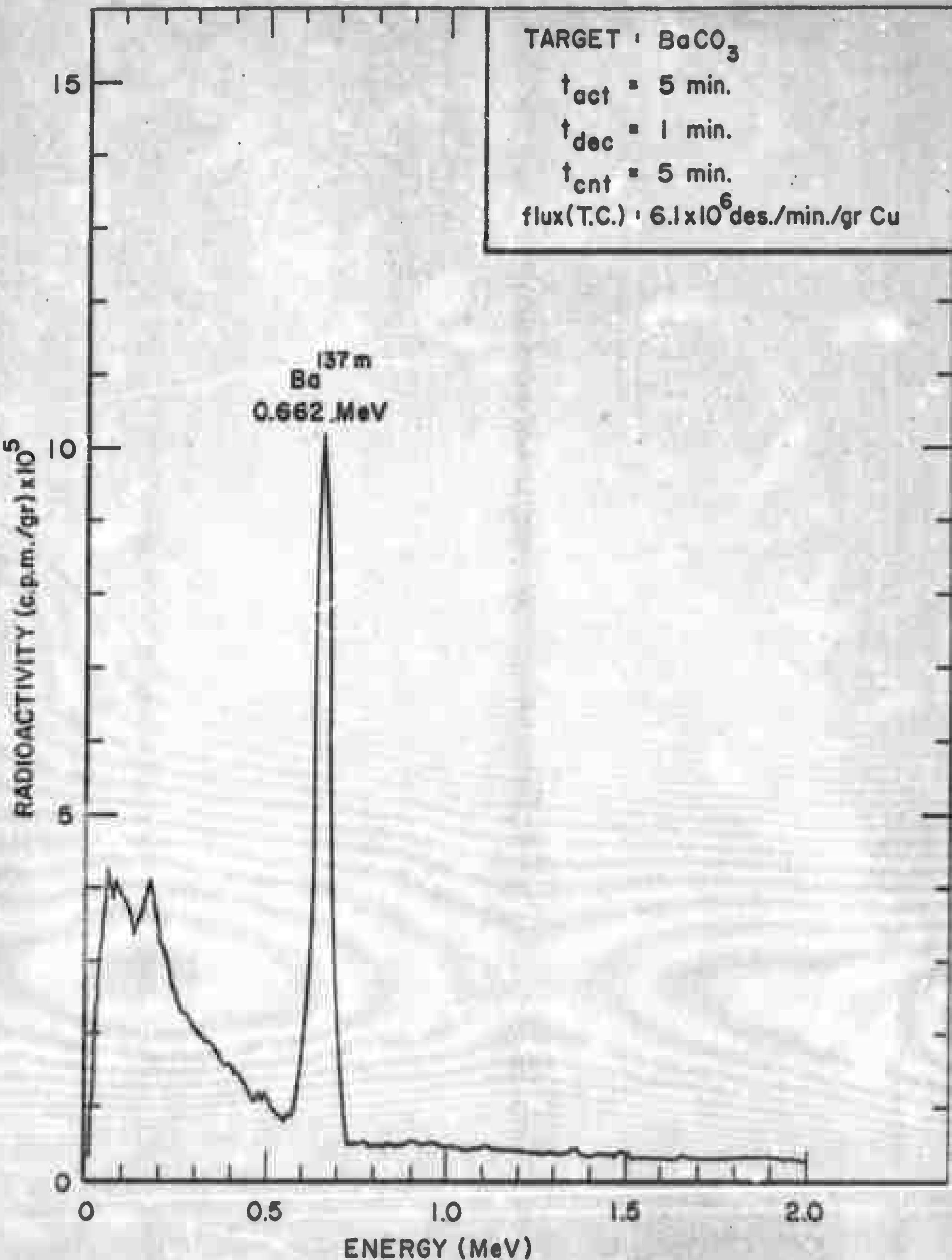

TARGET : $BaCO_3$
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) : 6.1×10^6 des./min./gr Cu
Ba^{137m}
0.662 MeV
RADIOACTIVITY (c.p.m./gr) x 10^5
15
10
5
0
0
0.5
1.0
1.5
2.0
ENERGY (MeV)

FIGURE I-Ba

TABLE II-Ba

PEAKS OBSERVED IN FIGURE I-Ba

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Ba	0.662	$Ba^{137}(n,n')Ba^{137m}$	2.6 m	
		$Ba^{138}(n,2n)Ba^{137m}$	2.6 m	

NOTE: -Xe^{127m} ($T_{1/2}$=75 sec) could be detected but the activity is very low.

-Ba^{135m} ($T_{1/2}$=.33 sec) not detected for 1 sec irradiation, 300 m sec decay and 1 sec counting time.

TABLE III-Ba

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT (mg)
0.662	5 m	1 m	5 m	5209	0.09

NOTE: Based on the 3σ criterion for calculating the detection limit, it was found to be 46μg. Experimentally, the limit is ~92 μg.

TABLE IV-Ba

POSSIBLE INTERFERING REACTIONS

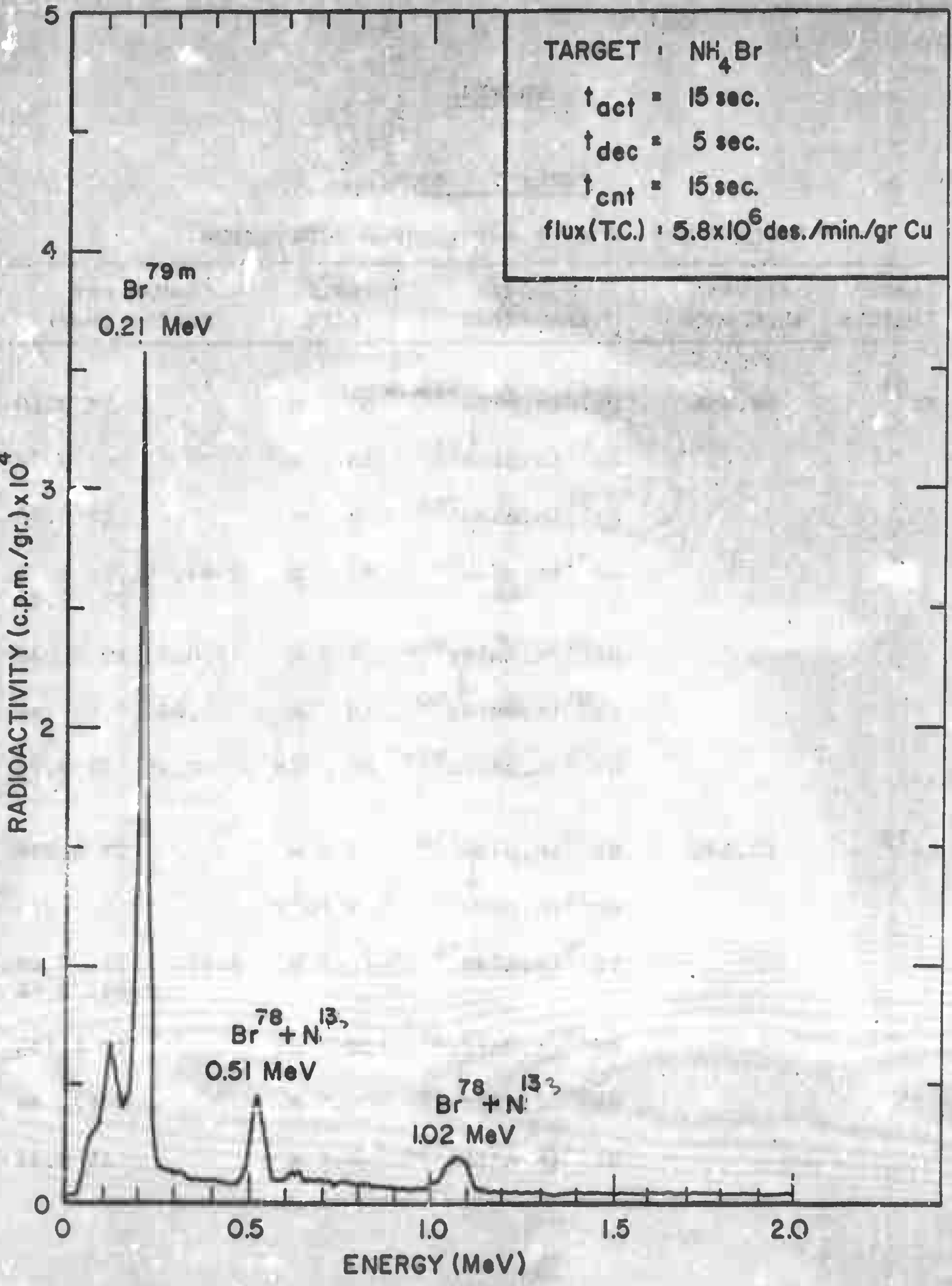
No detectable interferences could be derived for Barium from any other element.

BROMINE

TABLE I - Br

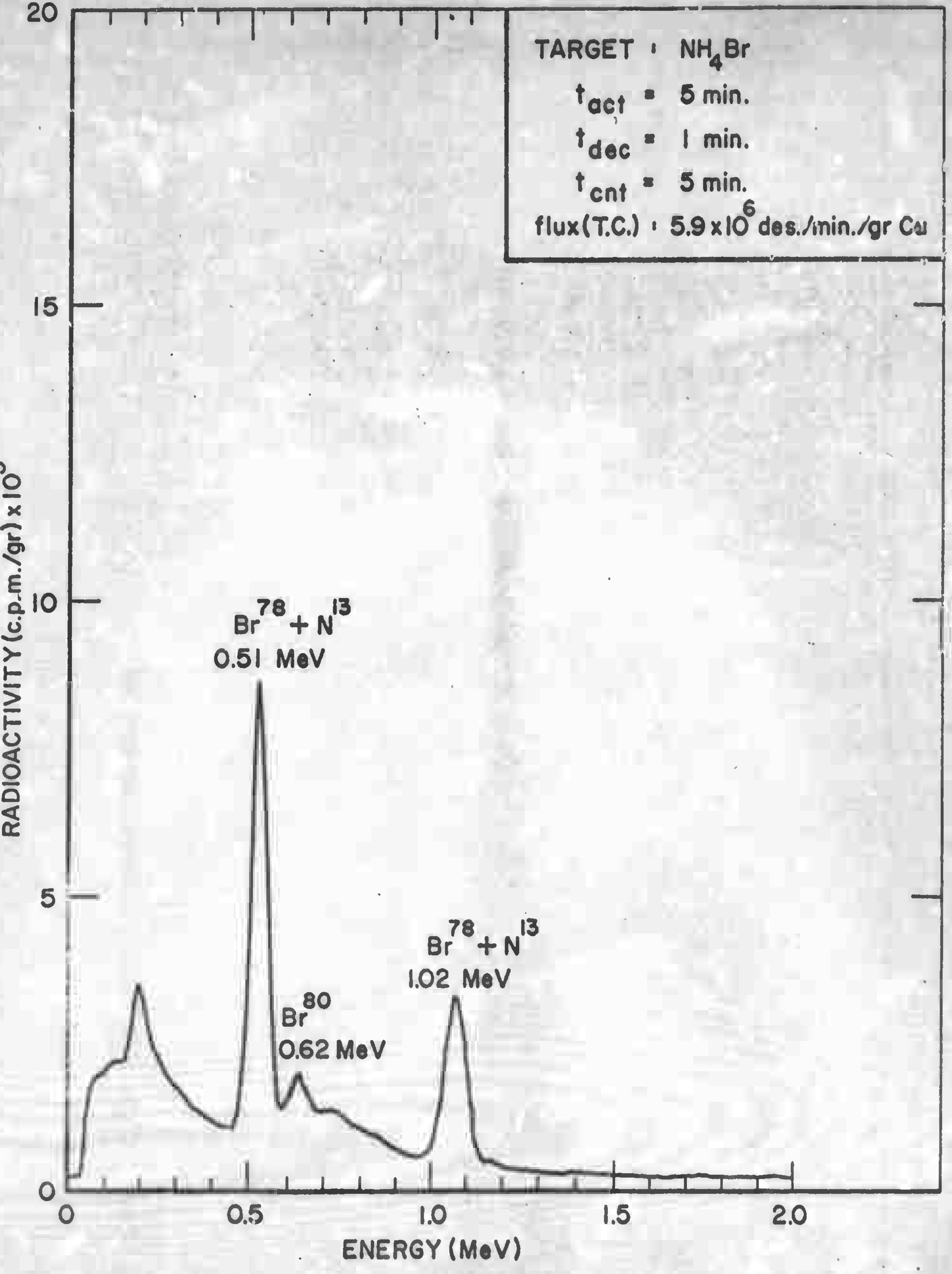
NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Br^{81}	49.46%	$Br^{81}(n,p)Se^{81m}$	57 m	IT 0.10
		$Br^{81}(n,p)Se^{81}$	18 m	0.28
		$Br^{81}(n,\alpha)As^{78m}$	6 m	IT 0.50
		$Br^{81}(n,\alpha)As^{78}$	91 m	0.62, 0.70, 1.31, 0.08, 2.68
		$Br^{81}(n,2n)Br^{80m}$	4.5 h	0.037, IT 0.049
		$Br^{81}(n,2n)Br^{80}$	18 m	0.62, 0.65, β+
		$Br^{81}(n,n')Br^{81m}$	37 μs	0.28, IT 0.27
Br^{79}	50.54%	$Br^{79}(n,p)Se^{79m}$	3.9 m	IT 0.096
		$Br^{79}(n,p)Se^{79}$	7×10^4 y	
		$Br^{79}(n,\alpha)As^{76}$	26.5 h	0.56, 1.21, 0.66, 0.64, 2.66
		$Br^{79}(n,2n)Br^{78m}$	120 μs	IT 0.149
		$Br^{79}(n,2n)Br^{78}$	6.5 m	0.62, β+
		$Br^{79}(n,n')Br^{79m}$	4.8 s	IT 0.21



TARGET : NH_4Br
t_{act} = 15 sec.
t_{dec} = 5 sec.
t_{cnt} = 15 sec.
flux (T.C.) : 5.8×10^6 des./min./gr Cu
Br^{79m}
0.21 MeV
$Br^{78} + N^{13}$
0.51 MeV
$Br^{78} + N^{13}$
1.02 MeV
RADIOACTIVITY (c.p.m./gr.) x 10^4
ENERGY (MeV)
0
1
2
3
4
5
0
0.5
1.0
1.5
2.0

FIGURE I-Br



TARGET : NH_4Br
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) : 5.9×10^6 des./min./gr Cu
RADIOACTIVITY (c.p.m./gr) $\times 10^5$
20
15
10
5
0
$Br^{78} + N^{13}$
0.51 MeV
Br^{80}
0.62 MeV
$Br^{78} + N^{13}$
1.02 MeV
0
0.5
1.0
1.5
2.0
ENERGY (MeV)

FIGURE II-Br

TABLE II-Br

PEAKS OBSERVED IN FIGURES I-Br and II-Br

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Br	0.21	$Br^{79}(n,n')Br^{79m}$	4.8 s	
	0.51	$Br^{79}(n,2n)Br^{78}$	6.5 m	
	1.02	$Br^{79}(n,2n)Br^{78}$	6.5 m	0.51 Mev coincidence sum peak
II-Br	0.51	$Br^{79}(n,2n)Br^{78}$	6.5 m	(1)
	0.62	$Br^{79}(n,2n)Br^{78}$	6.5 m	
	1.02	$Br^{79}(n,2n)Br^{78}$	6.5 m	0.51 Mev coincidence sum peak

(1) Br^{80} ($T_{1/2}$=18 min) not detected in these conditions

TABLE III-Br

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.21	15 s	5 s	15 s	106	1.0
0.51	5 m	1 m	5 m	3327 (1)	0.05
0.62	5 m	1 m	5 m	310	~0.50

(1) The contribution of nitrogen (35 counts) to the 0.51 Mev photopeak has been considered and has been subtracted from the total activity.

TABLE IV-Br

POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.51	Krypton	$Kr^{78}(n,p)Br^{78}$	(1)

This reaction has not been investigated because all the other radioisotopes emitting positrons are more probable interferences (see Appendix II in Section I).

CADMIUM

TABLE I - Cd

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Cd^{106}	1.22%	$Cd^{106}(n,p)Ag^{106m}$	8.3 d	0.51, 2.63
		$Cd^{106}(n,p)Ag^{106}$	24 m	0.51, β+
		$Cd^{106}(n,\alpha)Pd^{103}$	17 d	0.04, 0.052, 0.36
		$Cd^{106}(n,2n)Cd^{105}$	55 m	0.025, 2.32, β+
Cd^{108}	0.88%	$Cd^{108}(n,p)Ag^{108}$	5 y	0.72, 0.62, 0.43
		$Cd^{108}(n,p)Ag^{108}$	2.4 m	0.63, β-
		$Cd^{108}(n,\alpha)Pd^{105m}$	37 μs	0.32, IT 0.18
		$Cd^{108}(n,2n)Cd^{107}$	6.5 h	0.093, 0.033, 1.22, β+
Cd^{110}	12.39%	$Cd^{110}(n,p)Ag^{110m}$	260 d	0.66, 0.88, IT 0.12
		$Cd^{110}(n,p)Ag^{110}$	24 s	0.66
		$Cd^{110}(n,\alpha)Pd^{107m}$	22 s	IT 0.22
		$Cd^{110}(n,\alpha)Pd^{107}$	7×10^{6} y	
		$Cd^{110}(n,2n)Cd^{109m}$	12 μs	IT 0.058
		$Cd^{110}(n,2n)Cd^{109}$	1.3 y	0.088
Cd^{111}	12.75%	$Cd^{111}(n,p)Ag^{111m}$	74 s	IT 0.065

TABLE I - Cd (Cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
		$Cd^{111}(n,p)Ag^{111}$	7.5 d	0.34 0.25
		$Cd^{111}(n,n')Cd^{111m}$	49 m	0.247, IT 0.15
Cd^{112}	24.07%	$Cd^{112}(n,p)Ag^{112}$	3.2 h	0.62, 1.4, 0.69, 3.28
		$Cd^{112}(n,\alpha)Pd^{109m}$	4.8 m	IT 0.18
		$Cd^{112}(n,\alpha)Pd^{109}$	13.5 h	0.088
		$Cd^{112}(n,2n)Cd^{111m}$	49 m	0.247, IT 0.15
Cd^{113}	12.26%	$Cd^{113}(n,p)Ag^{113m}$	1.2 m	0.31, 0.70
		$Cd^{113}(n,p)Ag^{113}$	5.3 h	0.31, 0.12, 1.18
		$Cd^{113}(n,n')Cd^{113m}$	14 y	IT 0.27
Cd^{114}	28.86%	$Cd^{114}(n,p)Ag^{114}$	5 s	0.56
		$Cd^{114}(n,\alpha)Pd^{111m}$	5.5 h	1.69, 0.5, IT 0.17, 0.28
		$Cd^{114}(n,\alpha)Pd^{111}$	22 m	0.065
		$Cd^{114}(n,2n)Cd^{113m}$	14 y	IT 0.27
Cd^{116}	7.58%	$Cd^{116}(n,p)Ag^{106}$	2.5 m	1.8, 0.5, 2.6
		$Cd^{116}(n,\alpha)Pd^{113}$	1.5 m	
		$Cd^{116}(n,2n)Cd^{115m}$	43 d	0.94, 0.17, 1.56
		$Cd^{116}(n,2n)Cd^{115}$	2.3 d	0.52, 0.34

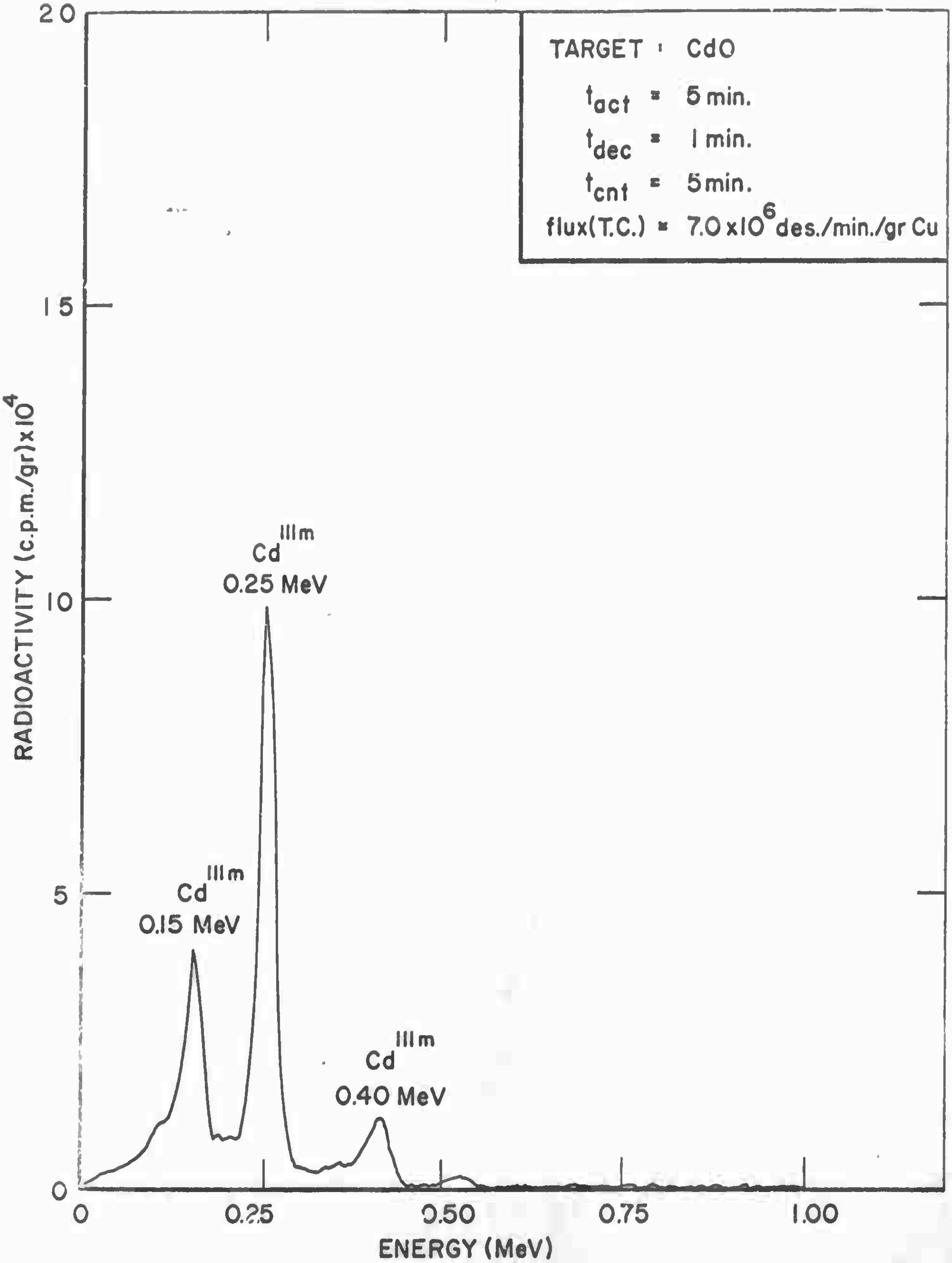

TARGET : CdO
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) = 7.0×10^6 des./min./gr Cu
RADIOACTIVITY (c.p.m./gr) $\times 10^4$
ENERGY (MeV)
Cd^{111m}
0.25 MeV
Cd^{111m}
0.15 MeV
Cd^{111m}
0.40 MeV
20
15
10
5
0
0
0.25
0.50
0.75
1.00

FIGURE I-Cd

TABLE II-Cd

PEAKS OBSERVED IN FIGURE I-Cd

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Cd	0.15	$Cd^{111}(n,n')Cd^{111m}$	49 m	
		$Cd^{112}(n,2n)Cd^{111m}$	49 m	
	0.25	$Cd^{111}(n,n')Cd^{111m}$	49 m	
		$Cd^{112}(n,2n)Cd^{111m}$	49 m	
	0.40	$Cd^{111}(n,n')Cd^{111m}$	49 m	sum peak of 0.15 + 0.25 Mev
		$Cd^{112}(n,2n)Cd^{111m}$	49 m	

NOTE: (a) Ag^{114} ($T_{½}$=5 sec) not detected for 15 sec irradiation, 5 sec decay and 15 sec counting time.

(b) Ag^{110} ($T_{½}$=24 sec) and Pd^{107m} ($T_{½}$=22 sec) not detected for 1 min irradiation, 20 sec decay and 1 minute counting time.

TABLE III-Cd

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT (mg)
0.25	5 m	1 m	5 m	363	0.39
0.15	5 m	1 m	5 m	107	1.2

TABLE IV-Cd

POSSIBLE INTERFERING REACTIONS

No detectable interferences could be derived for Cadmium from any other element.

CERIUM

TABLE I - Ce

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Ce^{136}	0.193%	$Ce^{136}(n,p)La^{136}$	9.5 m	0.83, β+
		$Ce^{136}(n,\alpha)Ba^{133m}$	39 h	0.012, IT 0.276
		$Ce^{136}(n,\alpha)Ba^{133}$	7.2 y	0.081, 0.36, 0.30, 0.08, 0.38
		$Ce^{136}(n,2n)Ce^{135}$	18 h	0.09, 0.27, β+
Ce^{138}	0.250%	$Ce^{138}(n,\alpha)Ba^{135m}$	0.35s	~0.7, ~0.8
		$Ce^{138}(n,\alpha)Ba^{135m}$	29 h	IT 0.268
		$Ce^{138}(n,2n)Ce^{137m}$	34 h	0.7, 0.8, 0.9, IT 0.26
		$Ce^{138}(n,2n)Ce^{137}$	9 h	0.01, 0.46
Ce^{140}	88.48%	$Ce^{140}(n,p)La^{140}$	40.2 h	1.6, 0.49, 0.81, 0.33, 0.065, 3.1
		$Ce^{140}(n,\alpha)Ba^{137m}$	2.6 m	IT 0.662
		$Ce^{140}(n,2n)Ce^{139m}$	55 s	IT 0.74
		$Ce^{140}(n,2n)Ce^{139}$	140 d	0.166
Ce^{142}	11.07%	$Ce^{142}(n,p)La^{142}$	1.4 h	0.64, 2.41, 2.55, 0.90, 0.86, 3.65
		$Ce^{142}(n,\alpha)Ba^{139}$	83 m	0.166, 1.43
		$Ce^{142}(n,2n)Ce^{141}$	32.5 d	0.145

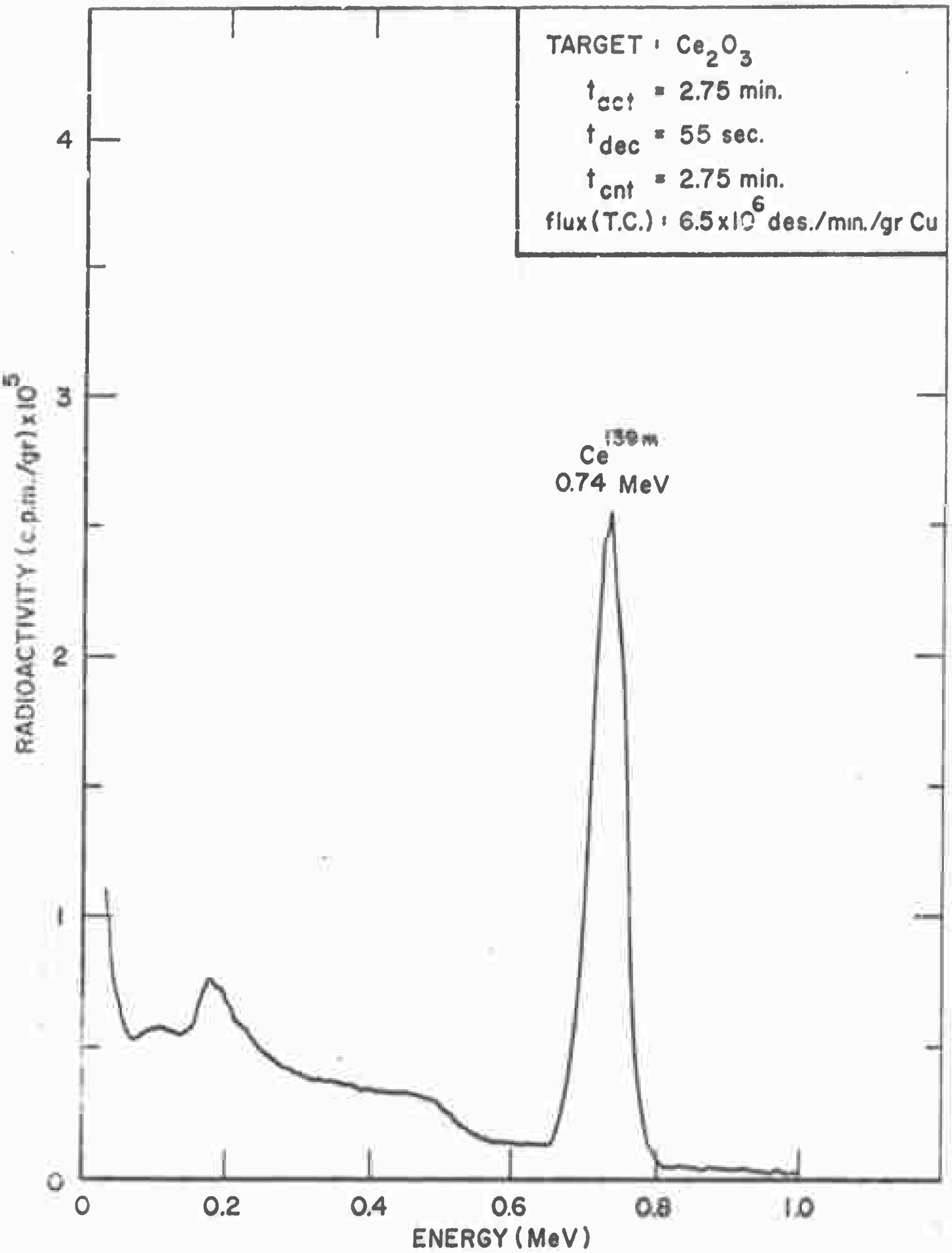

TARGET : Ce_2O_3
t_{act} = 2.75 min.
t_{dec} = 55 sec.
t_{cnt} = 2.75 min.
flux (T.C.) : 6.5×10^6 des./min./gr Cu
Ce^{139m}
0.74 MeV
RADIOACTIVITY (c.p.m./gr) $\times 10^5$
ENERGY (MeV)
0
1
2
3
4
0.2
0.4
0.6
0.8
1.0

FIGURE I-Ce

TABLE II-Ce

PEAKS OBSERVED IN FIGURE I-Ce

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Ce	0.74	$Ce^{140}(n,2n)Ce^{139m}$	55 s	

NOTE: Upon five minutes irradiation, no other characteristic peaks can be observed.

TABLE III-Ce

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT (mg)
0.74	2.75m	55 s	2.75m	1320	0.11

TABLE IV-Ce

POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.74	Neodymium	$Nd^{142}(n,\alpha)Ce^{139m}$	
	Neodymium	$Nd^{142}(n,2n)Nd^{141m}$	(1)
	Samarium	$Sm^{144}(n,2n)Sm^{143m}$	(1)
	Samarium	$Sm^{144}(n,\alpha)Nd^{141m}$	

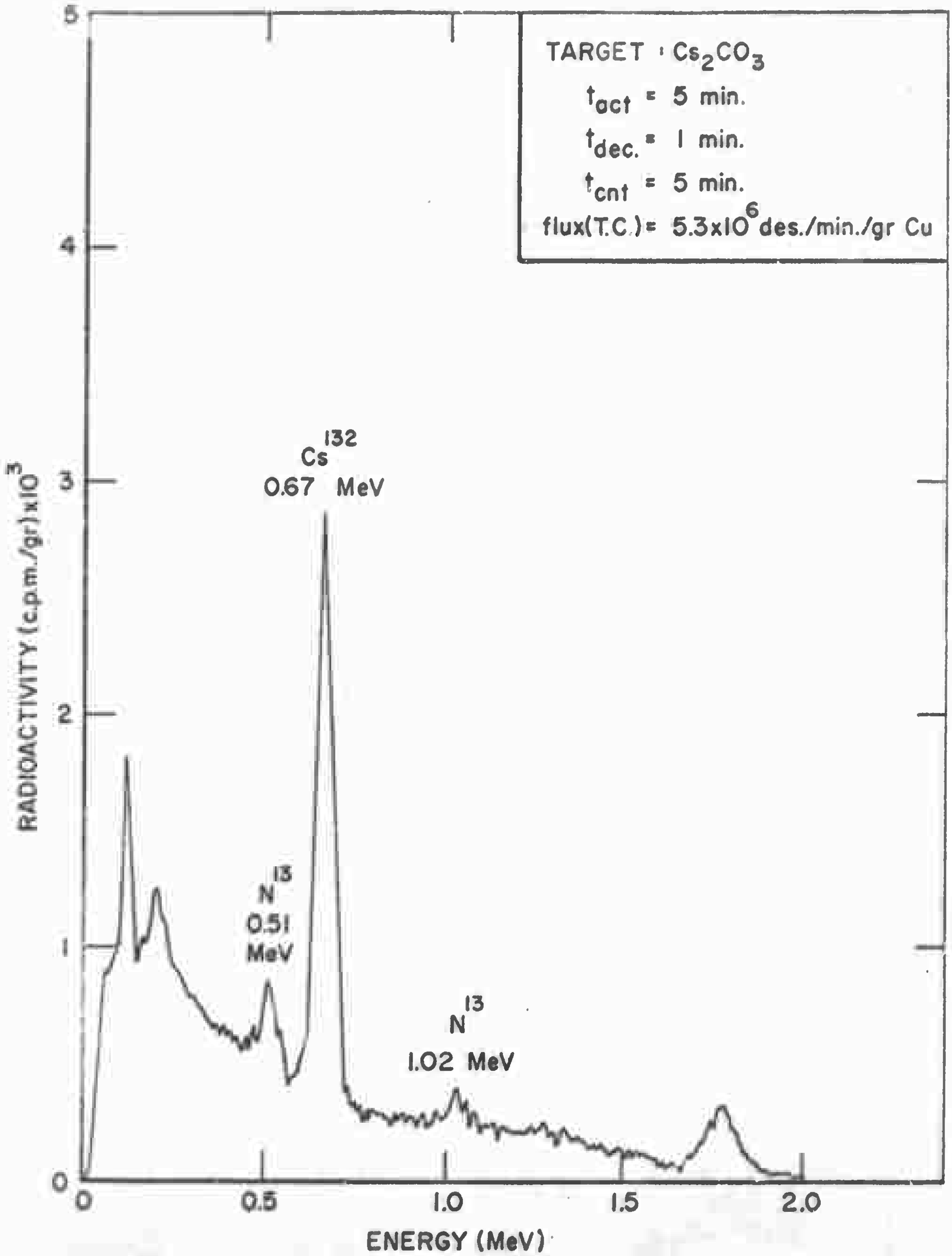
(1) Nd^{141m} and Sm^{143} have half lives respectively of 64 seconds and 60 seconds, making their identification from Ce^{139} very difficult.

CESIUM

TABLE I - Cs

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Cs^{133}	100%	$Cs^{133}(n,p)Xe^{133m}$	2.3 d	IT 0.233
		$Cs^{133}(n,p)Xe^{133}$	5.27d	0.081
		$Cs^{133}(n,\alpha)I^{130}$	12.5 h	0.66, 0.53, 0.74, 1.15, 0.41
		$Cs^{133}(n,2n)Cs^{132}$	6.58d	0.67, 0.46, 0.51, 2.0 β+



TARGET : Cs_2CO_3
t_{act} = 5 min.
$t_{dec.}$ = 1 min.
t_{cnt} = 5 min.
flux(T.C.) = 5.3×10^6 des./min./gr Cu
Cs^{132}
0.67 MeV
N^{13}
0.51
MeV
N^{13}
1.02 MeV
RADIOACTIVITY (c.p.m./gr) $\times 10^3$
ENERGY (MeV)
0
1
2
3
4
5
0
0.5
1.0
1.5
2.0

FIGURE I-Cs

TABLE II-Cs

PEAKS OBSERVED IN FIGURE I-Cs

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Cs	0.67	$Cs^{133}(n,2n)Cs^{132}$	6.58 d	

TABLE III-Cs

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT (mg)
0.67	5 m	1 m	5 m	13	8.5

TABLE IV-Cs

POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for cerium from any other element.

CHLORINE

TABLE I - Cl

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Cl^{35}	75.53%	$Cl^{35}(n,p)S^{35}$	86.7 d	
		$Cl^{35}(n,\alpha)P^{32}$	14.3 d	
		$Cl^{35}(n,2n)Cl^{34m}$	32.0 m	2.04, β+ IT 0.14
		$Cl^{35}(n,2n)Cl^{34}$	1.5 s	β+
Cl^{37}	24.47%	$Cl^{37}(n,p)S^{37}$	5.1 m	3.1
		$Cl^{37}(n,\alpha)P^{34}$	12.4 s	2.1, 4.0
		$Cl^{37}(n,2n)Cl^{36}$	3×10^5y	

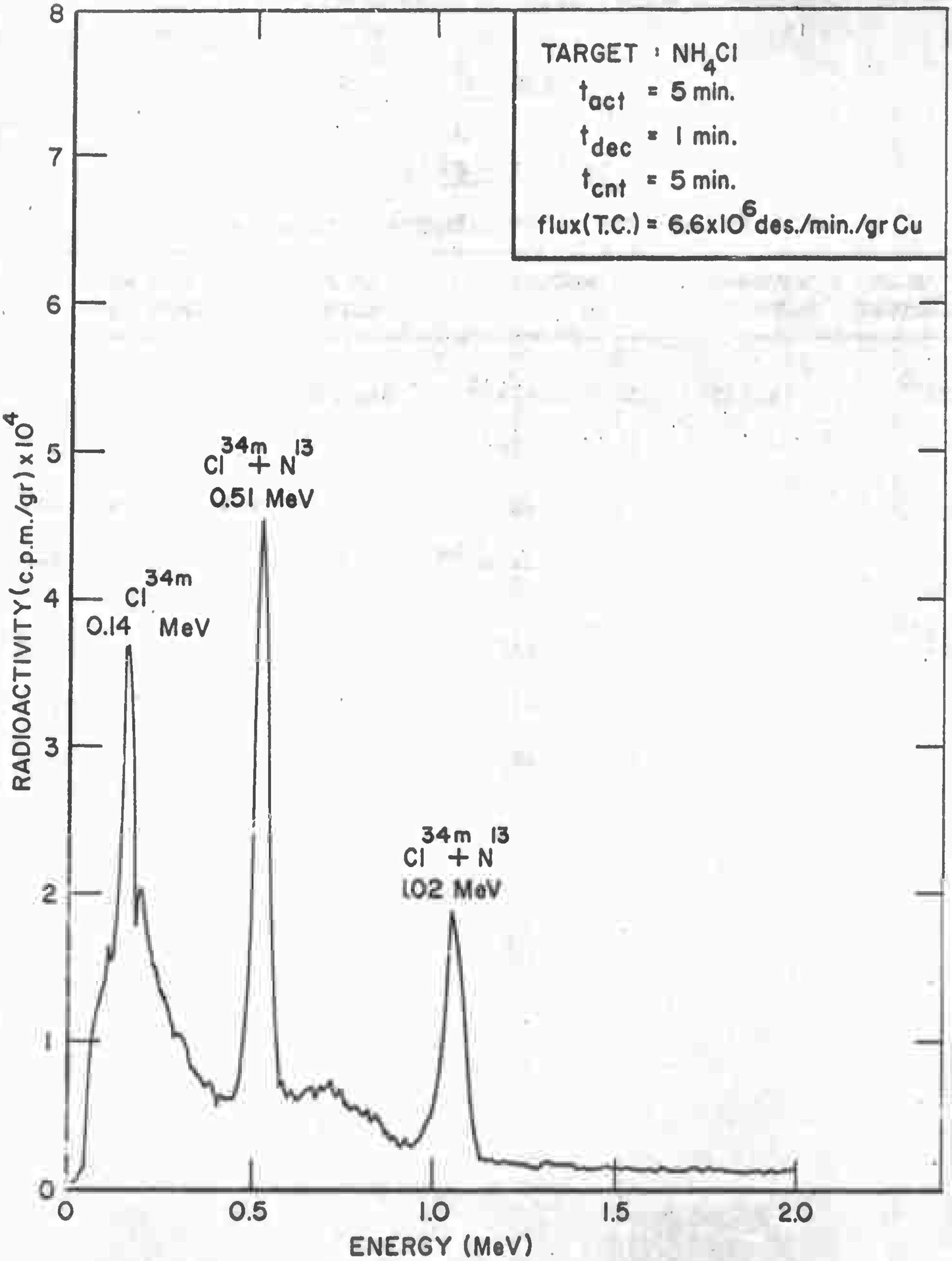
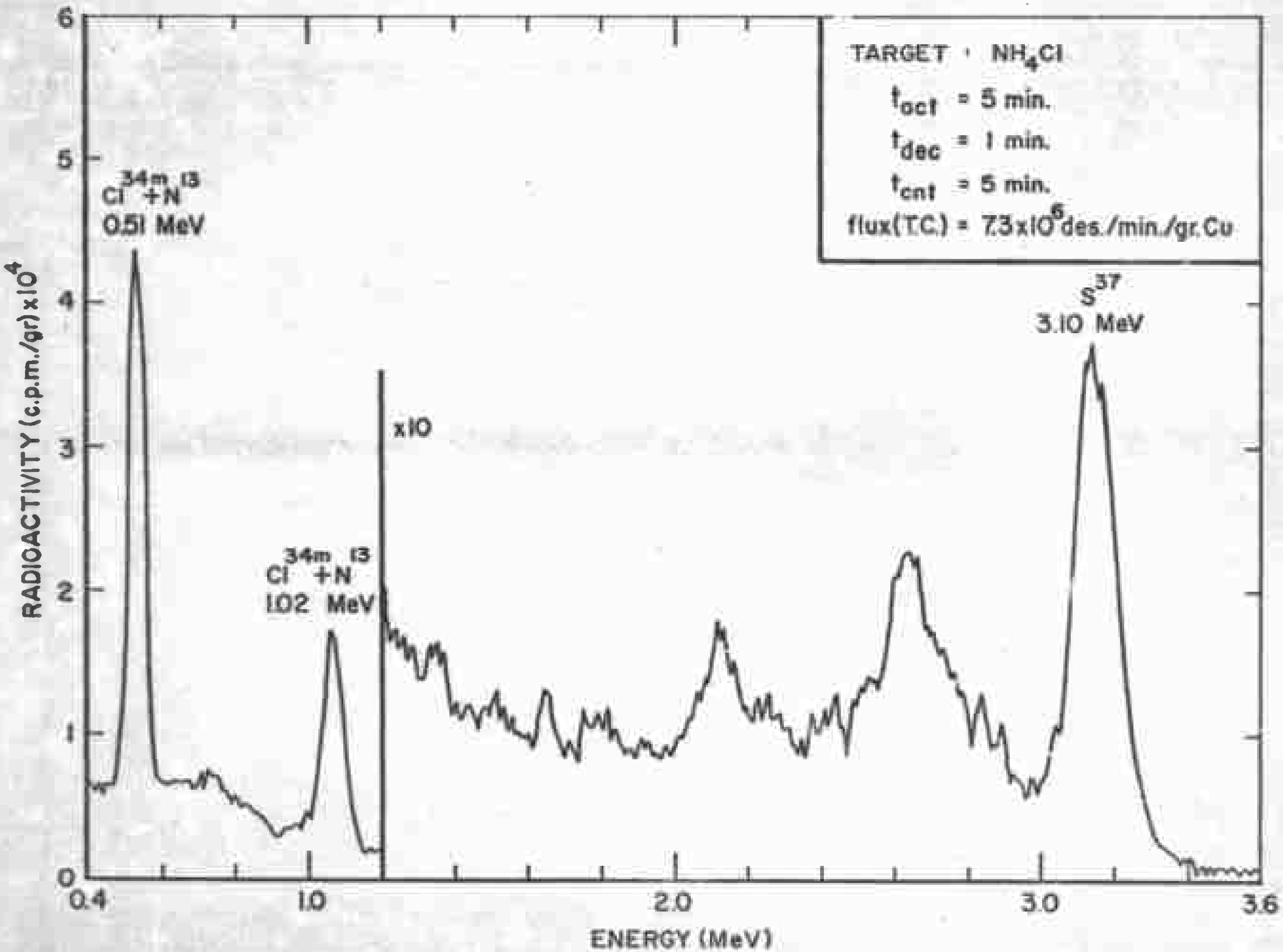

TARGET : NH_4Cl
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) = 6.6×10^6 des./min./gr Cu
$Cl^{34m} + N^{13}$
0.51 MeV
Cl^{34m}
0.14 MeV
$Cl^{34m} + N^{13}$
1.02 MeV
RADIOACTIVITY (c.p.m./gr) $\times 10^4$
ENERGY (MeV)
0
1
2
3
4
5
6
7
8
0
0.5
1.0
1.5
2.0

FIGURE I-Cl



TARGET : NH4Cl
tact = 5 min.
tdec = 1 min.
tcnt = 5 min.
flux(T.C.) = 7.3x10^6 des./min./gr.Cu
Cl34m + N13
0.51 MeV
Cl34m + N13
1.02 MeV
x10
S37
3.10 MeV
RADIOACTIVITY (c.p.m./gr) x10^4
ENERGY (MeV)
0
1
2
3
4
5
6
0.4
1.0
2.0
3.0
3.6

FIGURE II-C1

TABLE II-Cl

PEAKS OBSERVED IN FIGURE I-Cl

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Cl	0.14	$Cl^{35}(n,2n)Cl^{34m}$	32 m	
	0.51	$Cl^{35}(n,2n)Cl^{34m}$	32 m	
	1.02	$Cl^{35}(n,2n)Cl^{34m}$	32 m	0.51 Mev coincidence sum peak
II-Cl	0.51	$Cl^{35}(n,2n)Cl^{34m}$	32 m	
	1.02	$Cl^{35}(m,2n)Cl^{34m}$	32 m	
	3.10	$Cl^{37}(n,p)S^{37}$	5.1m	

NOTE: P^{34} ($T_{½}$ = 12.4 sec) is detectable for 37 sec irradiation, 12 sec decay and 37 sec counting time, but activity is low.

TABLE III-Cl

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.14	5 m	1 m	5 m	30	4.1
0.51	5 m	1 m	5 m	8(1)	21

(1) The contribution of nitrogen, present in NH_4Cl, to the 0.51 Mev photopeak is equal to 138 counts. This value has been subtracted from the N^{13} + Cl^{34m} activity.

TABLE IV-Cl

POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for chlorine from any other element.

For other positron emitting radioisotopes than Cl^{34m}, see Section I, Appendix II.

CHROMIUM

TABLE I - Cr

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Cr^{50}	4.31%	$Cr^{50}(n,2n)Cr^{49}$	42 m	0.09, 0.06, 0.15, $\beta+$
Cr^{52}	83.76%	$Cr^{52}(n,p)V^{52}$	3.77m	1.43
		$Cr^{52}(n,2n)Cr^{51}$	27.8 d	0.32
Cr^{53}	9.55%	$Cr^{53}(n,p)V^{53}$	2 m	1.01
Cr^{54}	2.38%	$Cr^{54}(n,p)V^{54}$	55 s	0.99, 0.84, 2.21
		$Cr^{54}(n,\alpha)Ti^{51}$	5.8 m	0.32, 0.93, 0.61

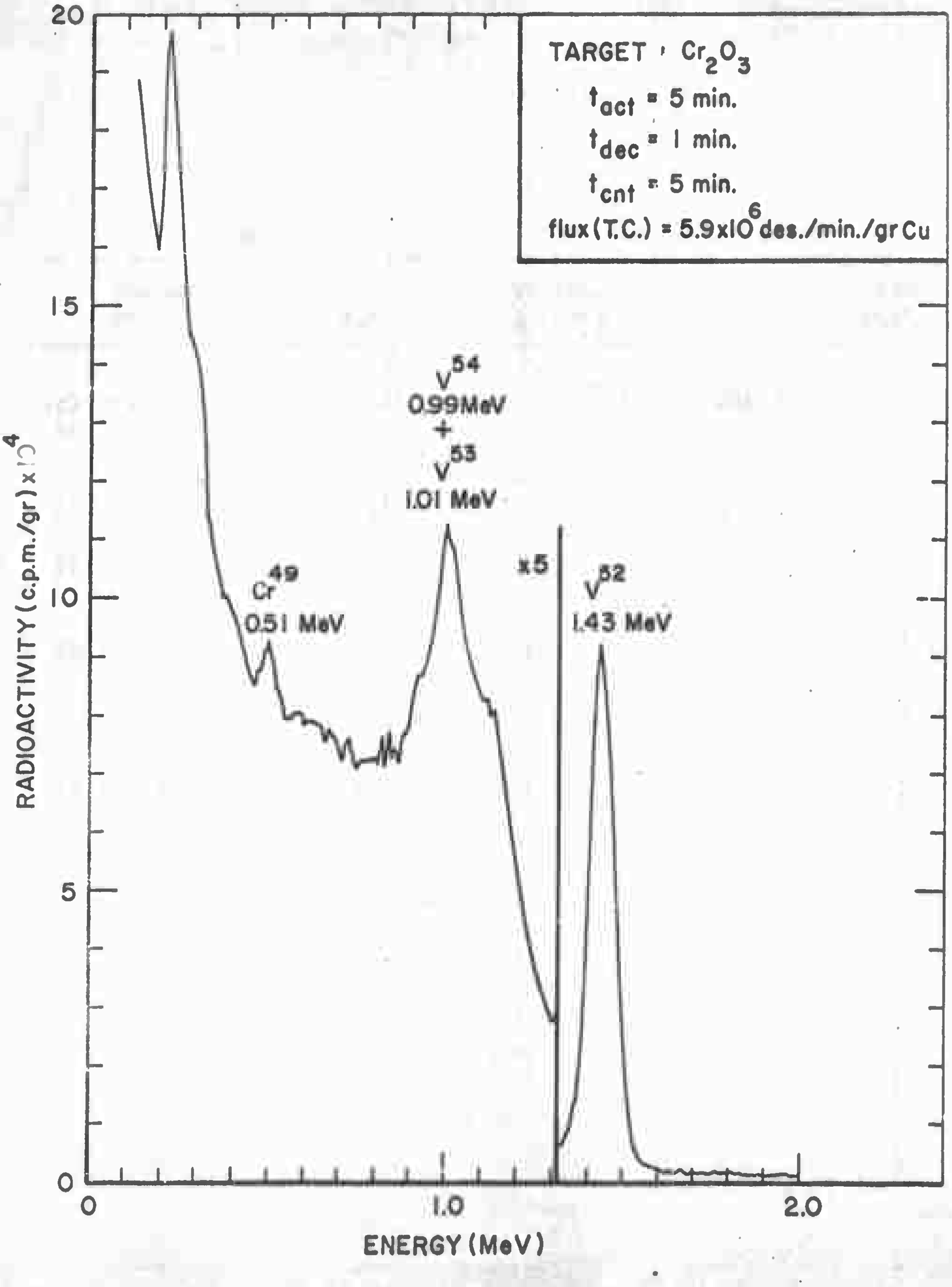

TARGET : Cr_2O_3
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux (T.C.) = 5.9×10^6 des./min./gr Cu
V^{54}
0.99 MeV
+
V^{53}
1.01 MeV
Cr^{49}
0.51 MeV
x5
V^{52}
1.43 MeV
RADIOACTIVITY (c.p.m./gr) x 10^4
ENERGY (MeV)
0
5
10
15
20
1.0
2.0

FIGURE I-Cr

TABLE II-Cr

PEAKS OBSERVED IN FIGURE I-Cr

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Cr	0.51	$Cr^{50}(n,2n)Cr^{49}$	42 m	
	0.99 + 1.01	$Cr^{54}(n,p)V^{54}$	55 s	(1)
		$Cr^{53}(n,p)V^{53}$	2 m	(1)
	1.43	$Cr^{52}(n,p)V^{52}$	3.77m	

(1) The half life found for the 1.01 +0.99 Mev photopeaks is 1.5 m, indicating that both isotopes V^{54} and V^{53} are present.

TABLE III-Cr

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
1.43	5 m	1 m	5 m	710	0.21

TABLE IV-Cr

POSSIBLE INTERFERING REACTIONS

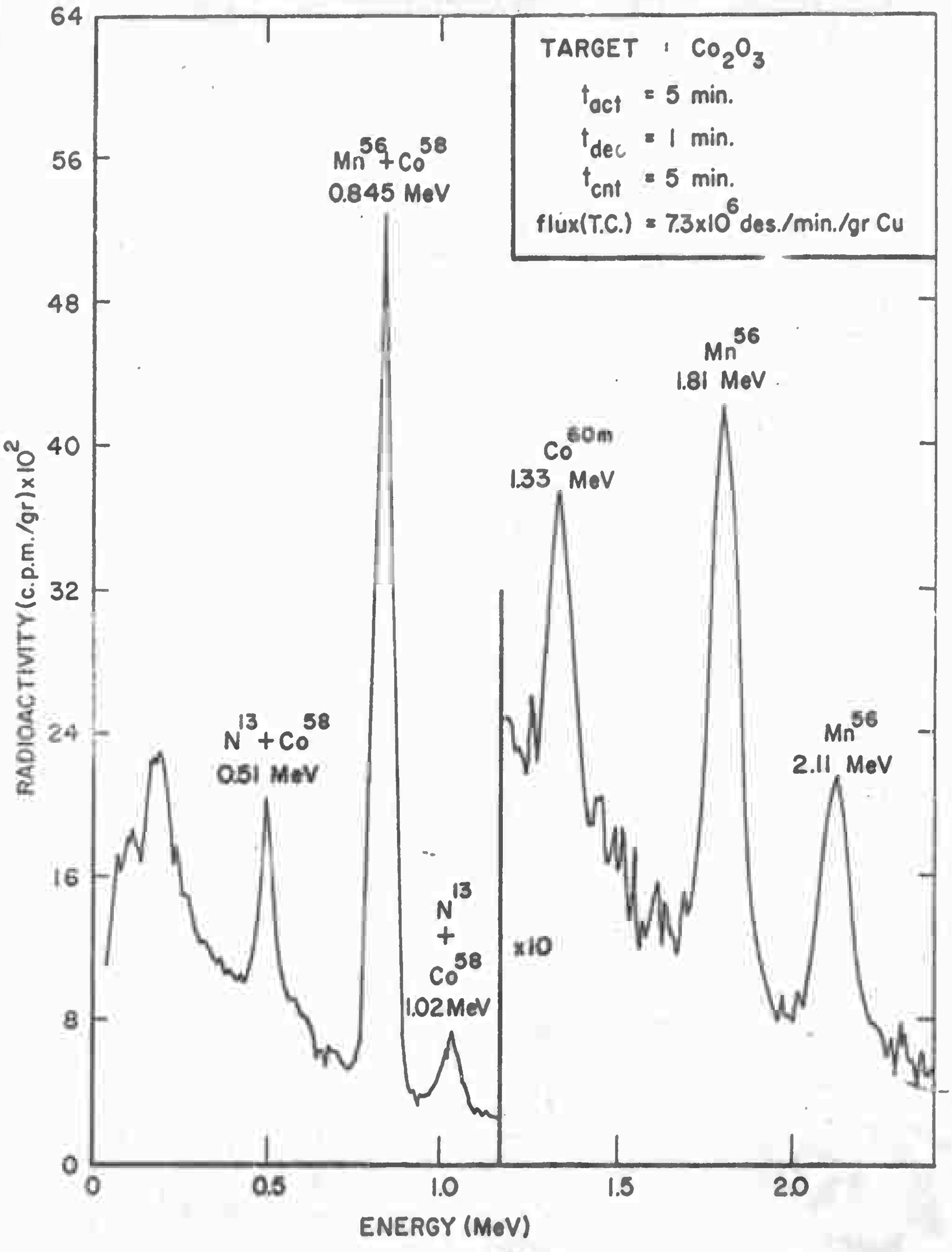
GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
1.43	Manganese	$Mn^{55}(n,\alpha)V^{52}$	
1.43	Vanadium	$V^{51}(n,\gamma)V^{52}$	

COBALT

TABLE I - Co

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY, (Mev)
Co^{59}	100%	$Co^{59}(n,p)Fe^{59}$	45 d	1.10, 1.29, 0.19
		$Co^{59}(n,\alpha)Mn^{56}$	2.58h	0.845, 1.81, 2.11
		$Co^{59}(n,2n)Co^{58m}$	9 h	IT 0.025
		$Co^{59}(n,2n)Co^{58}$	71 d	0.81, 1.65, $\beta+$



TARGET : Co_2O_3
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) = 7.3×10^6 des./min./gr Cu
$Mn^{56} + Co^{58}$
0.845 MeV
$N^{13} + Co^{58}$
0.51 MeV
N^{13} + Co^{58}
1.02 MeV
x10
Co^{60m}
1.33 MeV
Mn^{56}
1.81 MeV
Mn^{56}
2.11 MeV
RADIOACTIVITY (c.p.m./gr) x 10^2
ENERGY (MeV)
0
8
16
24
32
40
48
56
64
0.5
1.0
1.5
2.0

FIGURE I-Co

TABLE II-Co

PEAKS OBSERVED IN FIGURE I-Co

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Co	0.51	$Co^{59}(n,2n)Co^{58}$	71 d	(1)
	1.02	$Co^{59}(n,2n)Co^{58}$	71 d	0.51 Mev coincidence sum peak
	0.81	$Co^{59}(n,2n)Co^{58}$	71. d	Visible after decay of 24 hours
	0.845	$Co^{59}(n,\alpha)Mn^{56}$	2.58h	
	1.33	$Co^{59}(n,\gamma)Co^{60m}$	10.5 m	
	1.81	$Co^{59}(n,\alpha)Mn^{56}$	2.58h	
	2.11	$Co^{59}(n,\alpha)Mn^{56}$	2.58h	

(1) Most of0.51 Mev activity is due to the N^{13} activity in the vial. A decay curve on this gamma-ray peak shows, after 24 hours, a small activity due probably to the Co^{58}.

TABLE III-Co

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.80 + 0.845	5 m	1 m	5 m	28	4.3

TABLE IV-Co

POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.845	Iron	$Fe^{56}(n,p)Mn^{56}$	
0.845	Manganese	$Mn^{55}(n,\gamma)Mn^{56}$	

COPPER

TABLE I - Cu

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Cu^{63}	60.09%	$Cu^{63}(n,p)Ni^{63}$	92 y	
		$Cu^{63}(n,\alpha)Co^{60m}$	10.5 m	1.33, IT 0.059
		$Cu^{63}(n,\alpha)Co^{60}$	5.26y	1.33, 1.17
		$Cu^{63}(n,2n)Cu^{62}$	9.9 m	β+
Cu^{65}	30.91%	$Cu^{65}(n,p)Ni^{65}$	2.56h	1.49, 1.12, 0.37
		$Cu^{65}(n,\alpha)Co^{62m}$	1.9 m	
		$Cu^{65}(n,\alpha)Co^{62}$	13.9 m	1.17, 1.47, 1.74, 2.03
		$Cu^{65}(n,2n)Cu^{64}$	12.9 h	1.34, β+

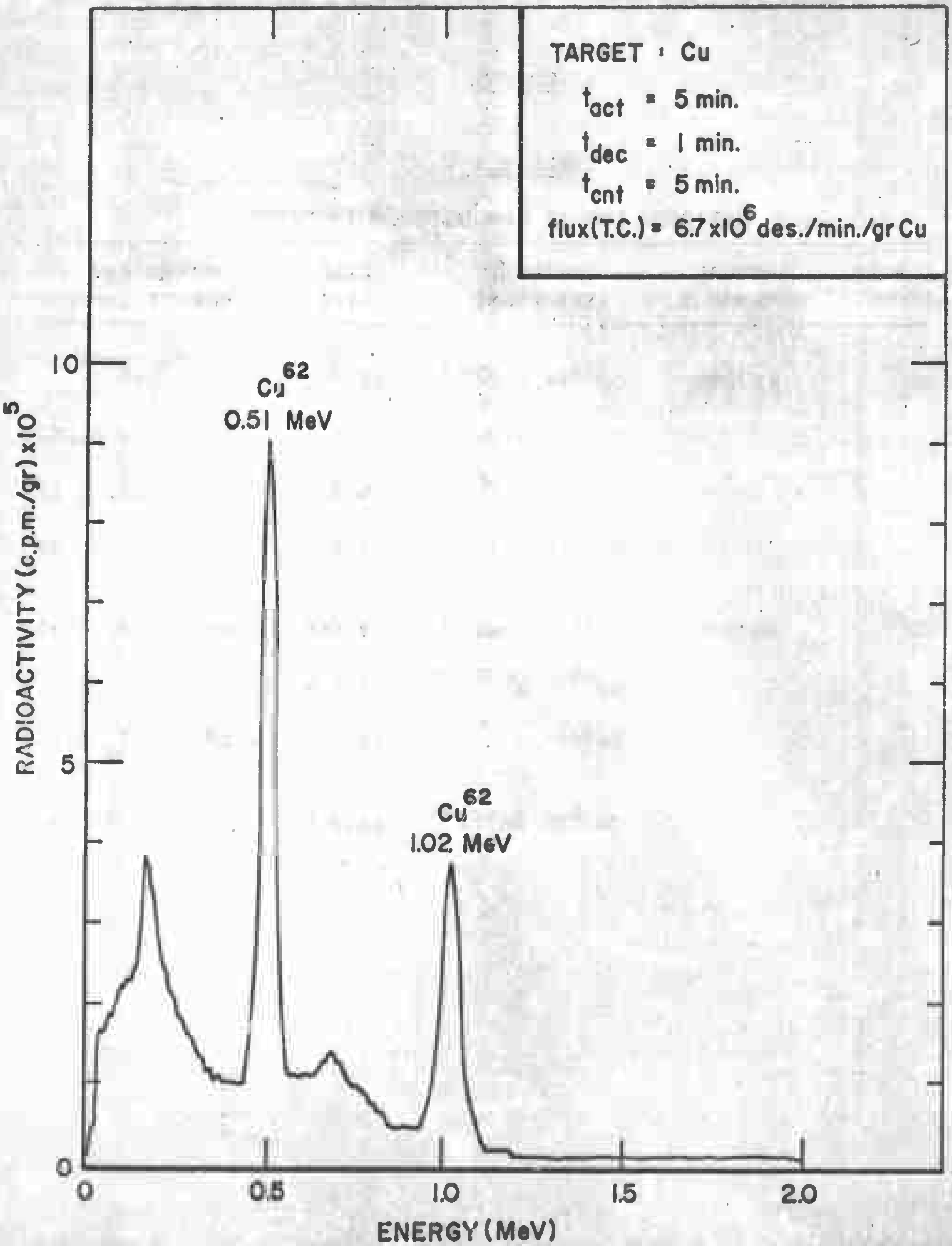

TARGET : Cu
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) = 6.7×10^6 des./min./gr Cu
Cu^{62}
0.51 MeV
Cu^{62}
1.02 MeV
RADIOACTIVITY (c.p.m./gr) $\times 10^5$
10
5
0
0
0.5
1.0
1.5
2.0
ENERGY (MeV)

FIGURE I-Cu

TABLE II-Cu

PEAKS OBSERVED IN FIGURE I-Cu

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Cu	0.51	$Cu^{63}(n,2n)Cu^{62}$	9.9 m	
	1.02	$Cu^{63}(n,2n)Cu^{62}$	9.9 m	0.51 Mev coincidence sum peak

TABLE III-Cu

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.51	5 m	1 m	5 m	3273	0.05

TABLE IV-Cu

POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.51	Nitrogen	$N^{14}(n,2n)N^{13}$	(1)
	Samarium	$Sm^{144}(n,2n)Sm^{143}$	(1)

(1) N^{13} and Sm^{143} have a half life respectively of 9.96 and 9 m, making their identification from Cu^{62} very difficult.

For other positron emitting radioisotopes, see Section I, Appendix II.

DYSPROSIUM

TABLE I - Dy

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Dy^{156}	0.052%	$Dy^{156}(n,p)Tb^{156m}$ ↓	5 h	IT 0.088 β+
		$Dy^{156}(n,p)Tb^{156}$	5.4 d	0.089, 0.53, 0.11, 2.0
		$Dy^{156}(n,\alpha)Gd^{153}$	240 d	0.097, 0.103, 0.070
		$Dy^{156}(n,2n)Dy^{155}$	10 h	0.23, 0.090, 1.67, β+
Dy^{158}	0.090%	$Dy^{158}(n,p)Tb^{158m}$ ↓	11 s	IT 0.111
		$Dy^{158}(n,p)Tb^{158}$	150 y	0.08, 1.19
		$Dy^{158}(n,2n)Dy^{157}$	8.5 h	0.327, 0.083, 0.061, 0.144, 0.182, 0.266
Dy^{160}	2.29%	$Dy^{160}(n,p)Tb^{160}$	72 d	0.97, 0.56, 0.88, 0.087, 1.34
		$Dy^{160}(n,2n)Dy^{159}$	144 d	0.058, 0.36, 0.29, 0.20
Dy^{161}	18.88%	$Dy^{161}(n,p)Tb^{161}$	6.9 d	0.049, 0.026, 0.020, 0.27
Dy^{162}	25.53%	$Dy^{162}(n,p)Tb^{162m}$ ↓	8 m	0.04, 0.89
		$Dy^{162}(n,p)Tb^{162}$	2 h	

DYSPROSIUM

TABLE I - (Cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
		$Dy^{162}(n,\alpha)Gd^{159}$	18 h	0.058, 0.36
Dy^{163}	24.97%	$Dy^{163}(n,p)Tb^{163m}$	16 m	0.08, 0.50
		$Dy^{163}(n,p)Tb^{163}$	6.5 h	0.33, 0.03, 0.16, 0.51
Dy^{164}	28.18%	$Dy^{164}(n,p)Tb^{164}$	1 d	
		$Dy^{164}(n,\alpha)Gd^{161}$	3.7 m	0.057, 0.078, 0.53

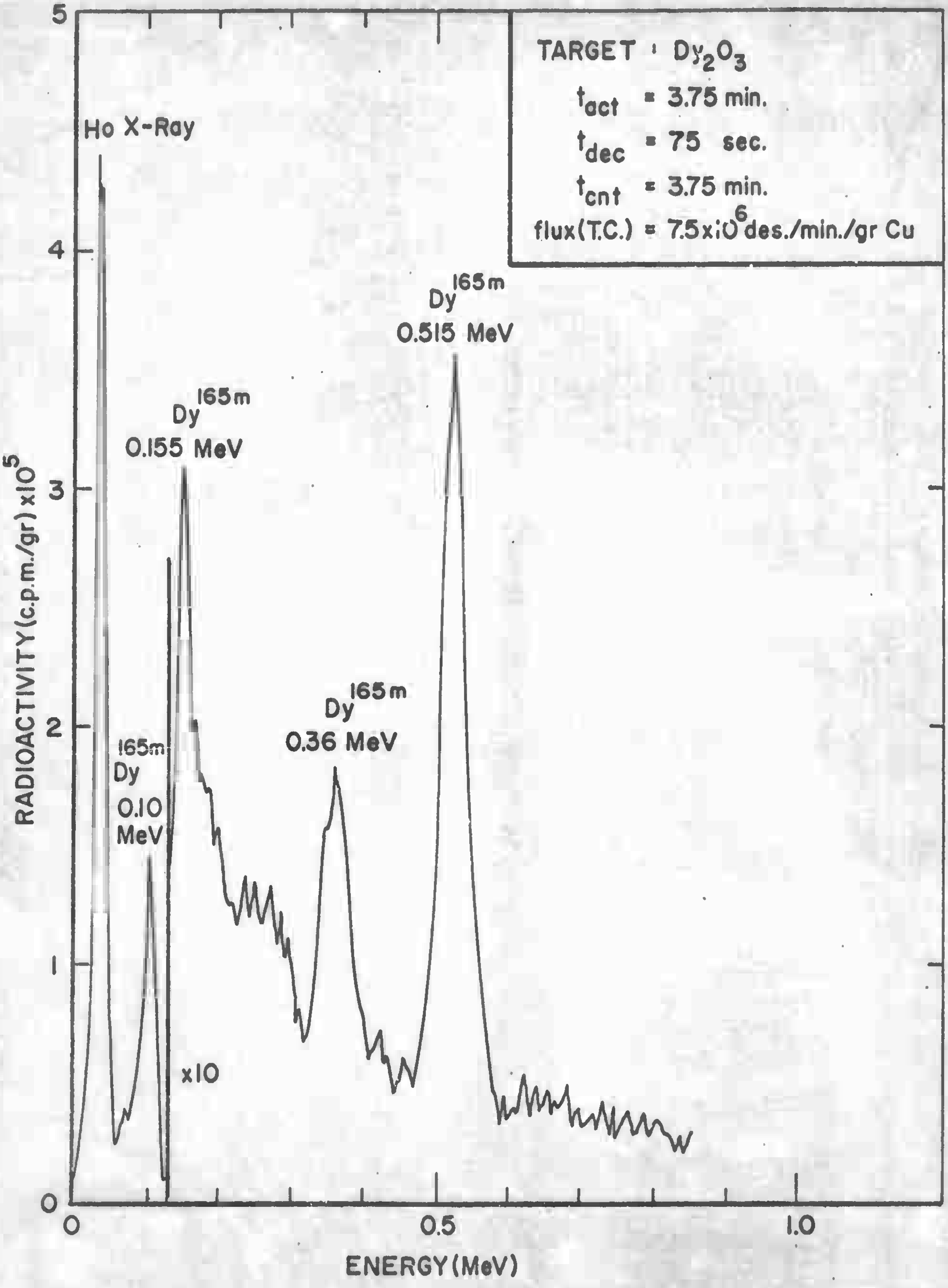

TARGET : Dy_2O_3
t_{act} = 3.75 min.
t_{dec} = 75 sec.
t_{cnt} = 3.75 min.
flux(T.C.) = 7.5×10^6 des./min./gr Cu
Ho X-Ray
Dy^{165m}
0.515 MeV
Dy^{165m}
0.155 MeV
Dy^{165m}
0.36 MeV
Dy^{165m}
0.10
MeV
x10
RADIOACTIVITY(c.p.m./gr) $\times 10^5$
ENERGY(MeV)
0
1
2
3
4
5
0
0.5
1.0

FIGURE I-Dy

TABLE II-Dy

PEAKS OBSERVED IN FIGURE I-Dy

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Dy	0.05			Ho x-ray
	0.108	$Dy^{164}(n,\gamma)Dy^{165m}$	75.4 s	
	0.155	$Dy^{164}(n,\gamma)Dy^{165m}$	75.4 s	
	0.36	$Dy^{164}(n,\gamma)Dy^{165m}$	75.4 s	
	0.515	$Dy^{164}(n,\gamma)Dy^{165m}$	75.4 s	

TABLE III-Dy

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.05	3.75 m	75 s	3.75 m	1390	0.10
0.108	3.75 m	75 s	3.75 m	388	0.25

TABLE IV-Dy

POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for dysprosium from any other element.

ERBIUM

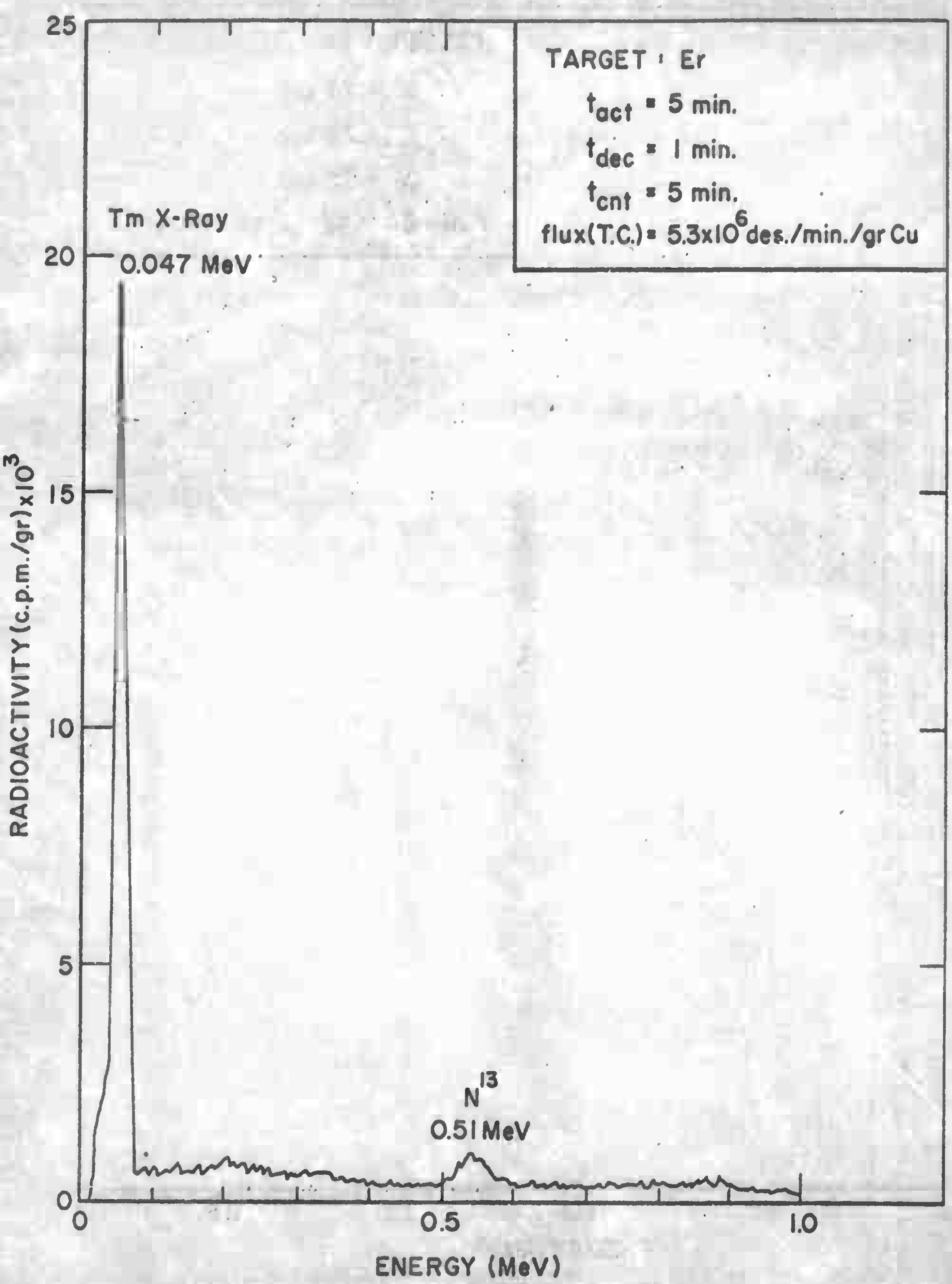
TABLE I - Er

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Er^{162}	0.136%	$Er^{162}(n,p)Ho^{162m}$	68 m	0.08, 0.04, 1.34, IT 0.01
		$Er^{162}(n,p)Ho^{162}$	12 m	0.08, β+
		$Er^{162}(n,\alpha)Dy^{159}$	144 d	0.058, 0.36, 0.29, 0.20
		$Er^{162}(n,2n)Er^{161}$	3.1 h	0.067, 0.211, 0.83, 1.12 β+
Er^{164}	1.56%	$Er^{164}(n,p)Ho^{164}$	35 m	0.073, 0.09, 0.037, IT 0.046
		$Er^{164}(n,2n)Er^{163}$	75 m	0.43, 1.1, 0.3, β+
Er^{166}	33.41%	$Er^{166}(n,p)Ho^{166m}$	1.2×10^3y	0.08, 0.184, 0.71
		$Er^{166}(n,p)Ho^{166}$	27.2 h	0.08, 1.4, 0.7, 1.8
		$Er^{166}(n,2n)Er^{165}$	10.36h	
Er^{167}	22.94%	$Er^{167}(n,p)Ho^{167}$	3.1 h	0.079, 0.083, 0.057, 0.074, 0.532
		$Er^{167}(n,n')Er^{167m}$	2.5 s	IT 0.208

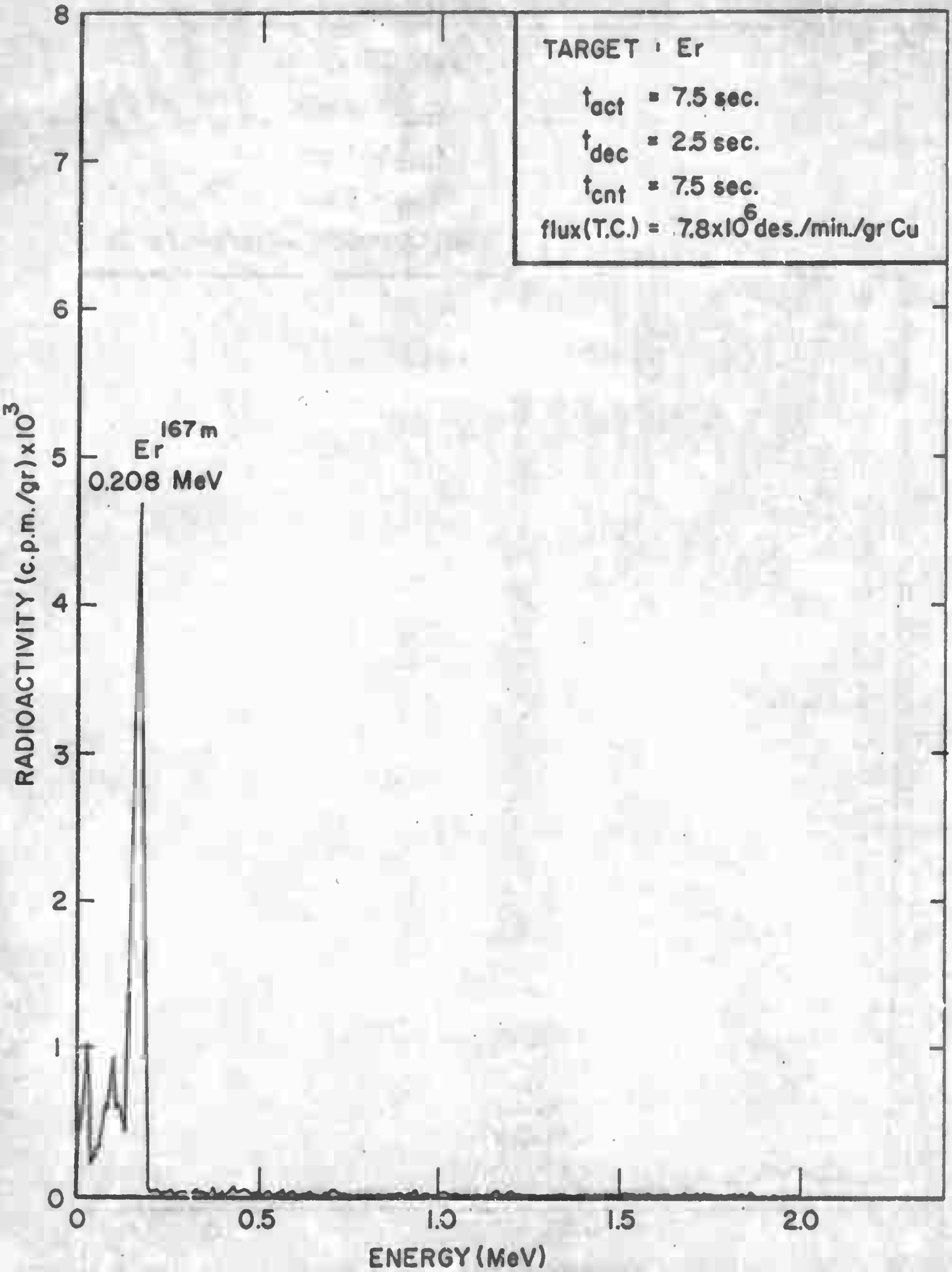
TABLE I - Er (Cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Er^{168}	27.07	$Er^{168}(n,p)Ho^{168}$	3 m	0.85
		$Er^{168}(n,\alpha)Dy^{165m}$	75.4 s	0.51, 0.36, 0.15, IT 0.108
		$Er^{168}(n,\alpha)Dy^{165}$	2.35h	0.095, 0.028, 1.1
		$Er^{168}(n,2n)Er^{167m}$	2.5 s	IT 0.208
Er^{170}	14.88%	$Er^{170}(n,p)Ho^{170}$	44 s	0.43
		$Er^{170}(n,\alpha)Dy^{167}$	4.4 m	0.19, 0.26, 0.31, 0.51, 0.57
		$Er^{170}(n,2n)Er^{169}$	9.4 d	0.008



TARGET : Er
t act = 5 min.
t dec = 1 min.
t cnt = 5 min.
flux(T.C.) = 5.3x10^6 des./min./gr Cu
Tm X-Ray
0.047 MeV
N^13
0.51 MeV
RADIOACTIVITY (c.p.m./gr) x 10^3
ENERGY (MeV)
0
5
10
15
20
25
0
0.5
1.0

FIGURE I-Er



TARGET : Er
t_{act} = 7.5 sec.
t_{dec} = 2.5 sec.
t_{cnt} = 7.5 sec.
flux(T.C.) = 7.8×10^6 des./min./gr Cu
Er^{167m}
0.208 MeV
RADIOACTIVITY (c.p.m./gr) $\times 10^3$
ENERGY (MeV)
0
0.5
1.0
1.5
2.0
1
2
3
4
5
6
7
8

FIGURE II-Er

TABLE II-Er

PEAKS OBSERVED IN FIGURE I-Er

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Er	0.208	$Er^{167}(n,n')Er^{167m}$	2.5 s	
II-Er	0.049			Tm x-ray

TABLE III-Er

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg) 1X	5X
0.049	5 m	1 m	5 m	58	1.8	
0.208	7.5s	2.5 s	7.5 s	8	4	1.7

NOTE: Because of the very short half life of Er^{167m}, five irradiation have been performed, and their spectra accumulated. The seventh column refers to the sensitivities obtained after five irradiations.

TABLE IV-Er

POSSIBLE INTERFERING REACTIONS

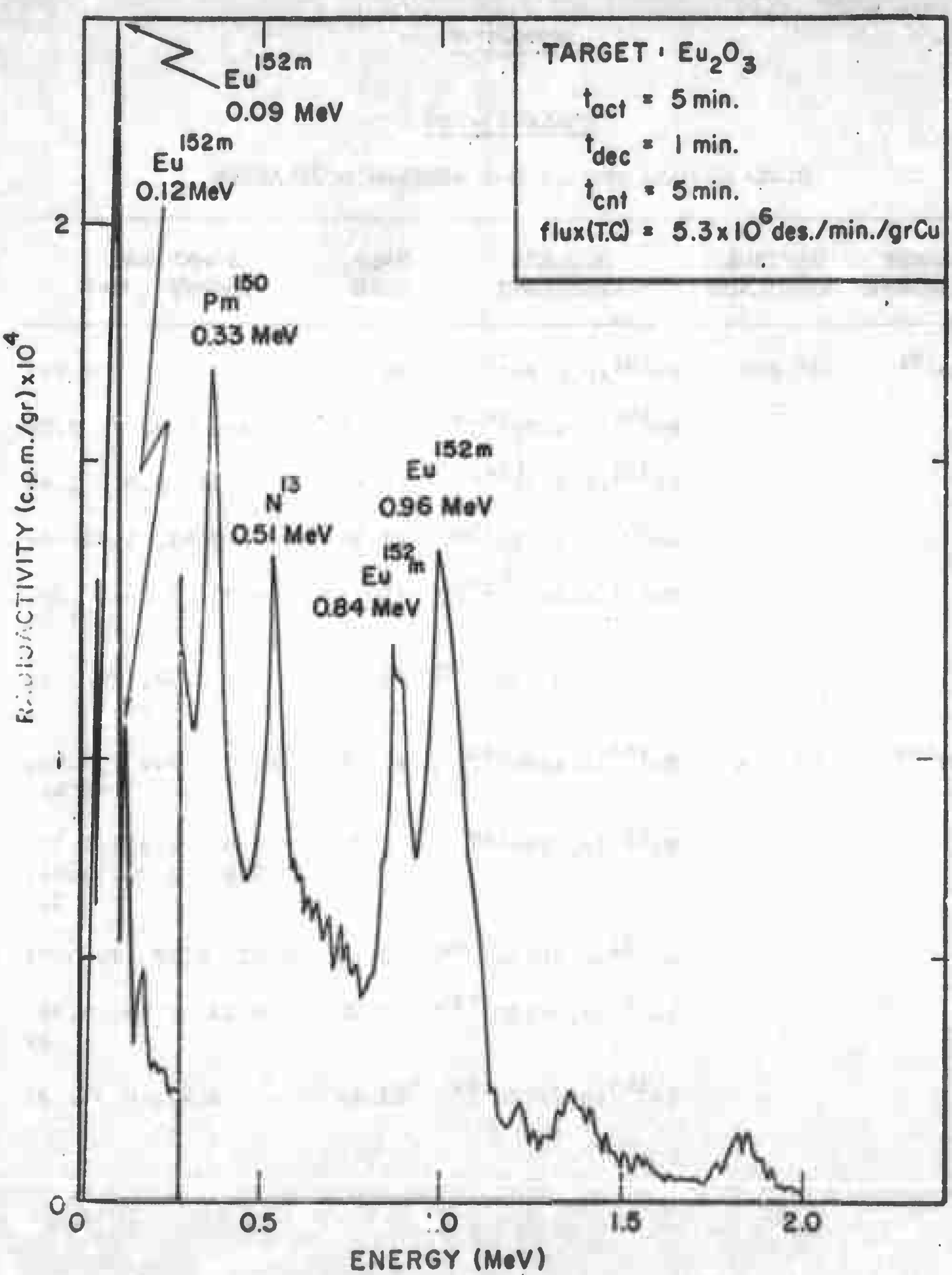
No detectable interference could be derived for Erbium from any other element.

EUROPIUM

TABLE I - Eu

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Eu^{151}	47.82%	$Eu^{151}(n,p)Sm^{151}$	90 y	0.022
		$Eu^{151}(n,\alpha)Pm^{148m}$	41 d	0.08, 1.0, IT 0.06
		$Eu^{151}(n,\alpha)Pm^{148}$	5.4d	0.55, 0.91, 1.46
		$Eu^{151}(n,2n)Eu^{150m}$	12.8h	0.33, 1.99, β+
		$Eu^{151}(n,2n)Eu^{150}$	25 y	0.33, 0.44, 0.30, 1.64
		$Eu^{151}(n,n')Eu^{151m}$	58 μs	0.02, IT 0.18
Eu^{153}	52.18%	$Eu^{153}(n,p)Sm^{153}$	47 h	0.103, 0.07, 0.02, 0.64
		$Eu^{153}(n,\alpha)Pm^{150}$	2.7h	0.33, 1.17, 1.33, 0.83, 1.75, 0.41, 3.1
		$Eu^{153}(n,2n)Eu^{152m}$	96 m	0.02, 0.09, IT 0.04
		$Eu^{153}(n,2n)Eu^{152m}$	9.3h	0.12, 0.84, 0.96, β+
		$Eu^{153}(n,2n)Eu^{152}$	12.4y	0.12, 0.34, β+



TARGET : Eu_2O_3
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C) = 5.3×10^6 des./min./grCu
Eu^{152m} 0.09 MeV
Eu^{152m} 0.12 MeV
Pm^{150} 0.33 MeV
N^{13} 0.51 MeV
Eu^{152m} 0.84 MeV
Eu^{152m} 0.96 MeV
RADIOACTIVITY (c.p.m./gr) x 10^4
ENERGY (MeV)
0
1
2
0
0.5
1.0
1.5
2.0

FIGURE I-Eu

TABLE II-Eu

PEAKS OBSERVED IN FIGURE I-Eu

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Eu	0.09	$Eu^{153}(n,2n)Eu^{152m}$	96 m	
	0.12	$Eu^{153}(n,2n)Eu^{152m}$	9.3 h	
	0.33	$Eu^{153}(n,\alpha)Pm^{150}$	2.7 h	
	0.84	$Eu^{153}(n,2n)Eu^{152m}$	9.3 h	
	0.96	$Eu^{163}(n,2n)Eu^{152m}$	9.3 h	

TABLE III-Eu

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/ mg/T_{cnt}	DETECTION LIMIT, mg
0.09	5 m	1 m	5 m	32	2.9
0.33	5 m	1 m	5 m	6	18

TABLE IV-Eu

POSSIBLE INTERFERING REACTIONS

No detectable interferences could be derived fro europium from any other element.

FLUORINE

TABLE I - F

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
F^{19}	100%	$F^{19}(n,p)O^{19}$	29 s	0.20, 1.36
		$F^{19}(n,\alpha)N^{16}$	7.35s	6.13, 7.12
		$F^{19}(n,2n)F^{18}$	110 m	0.65, β+

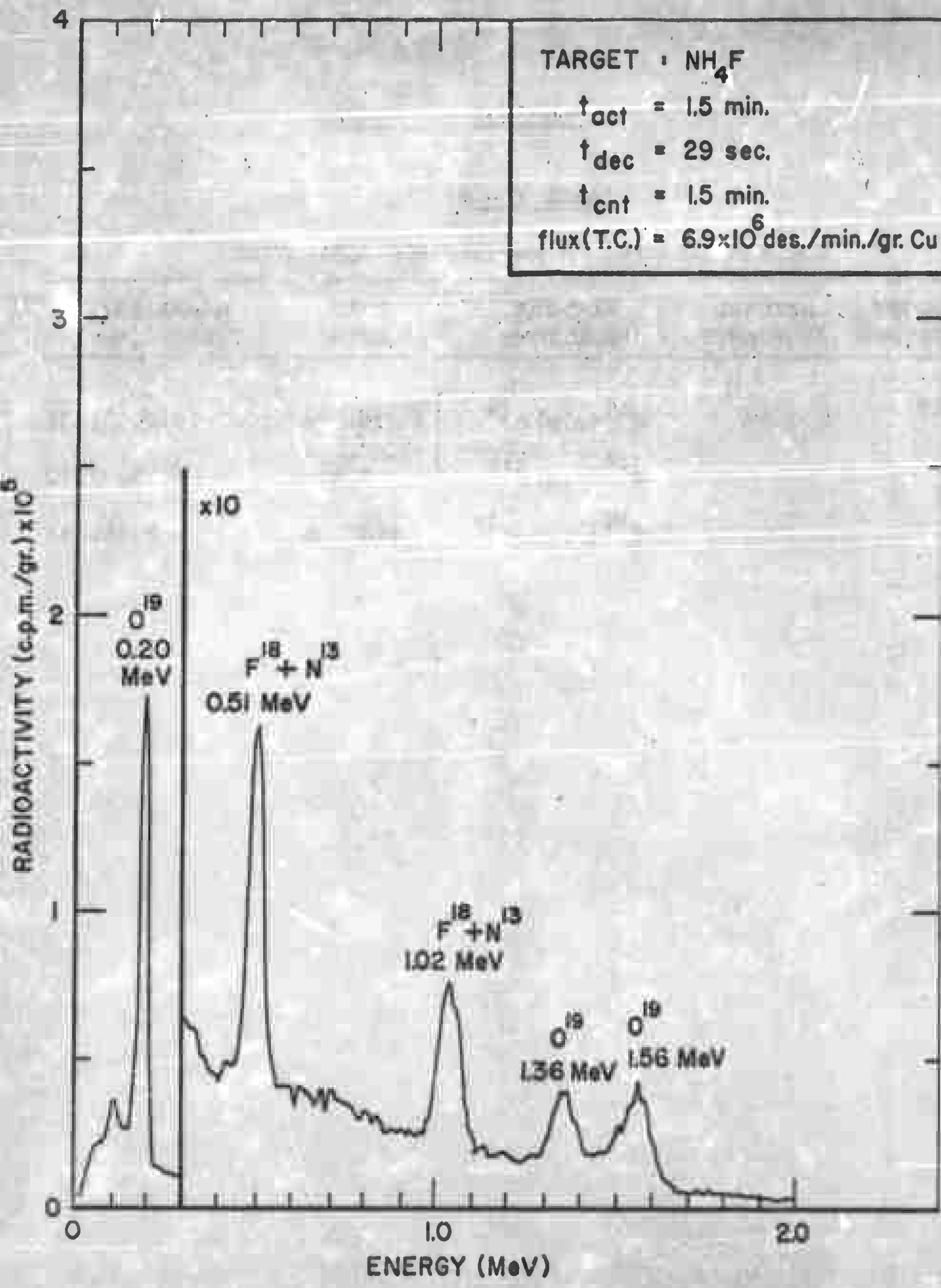
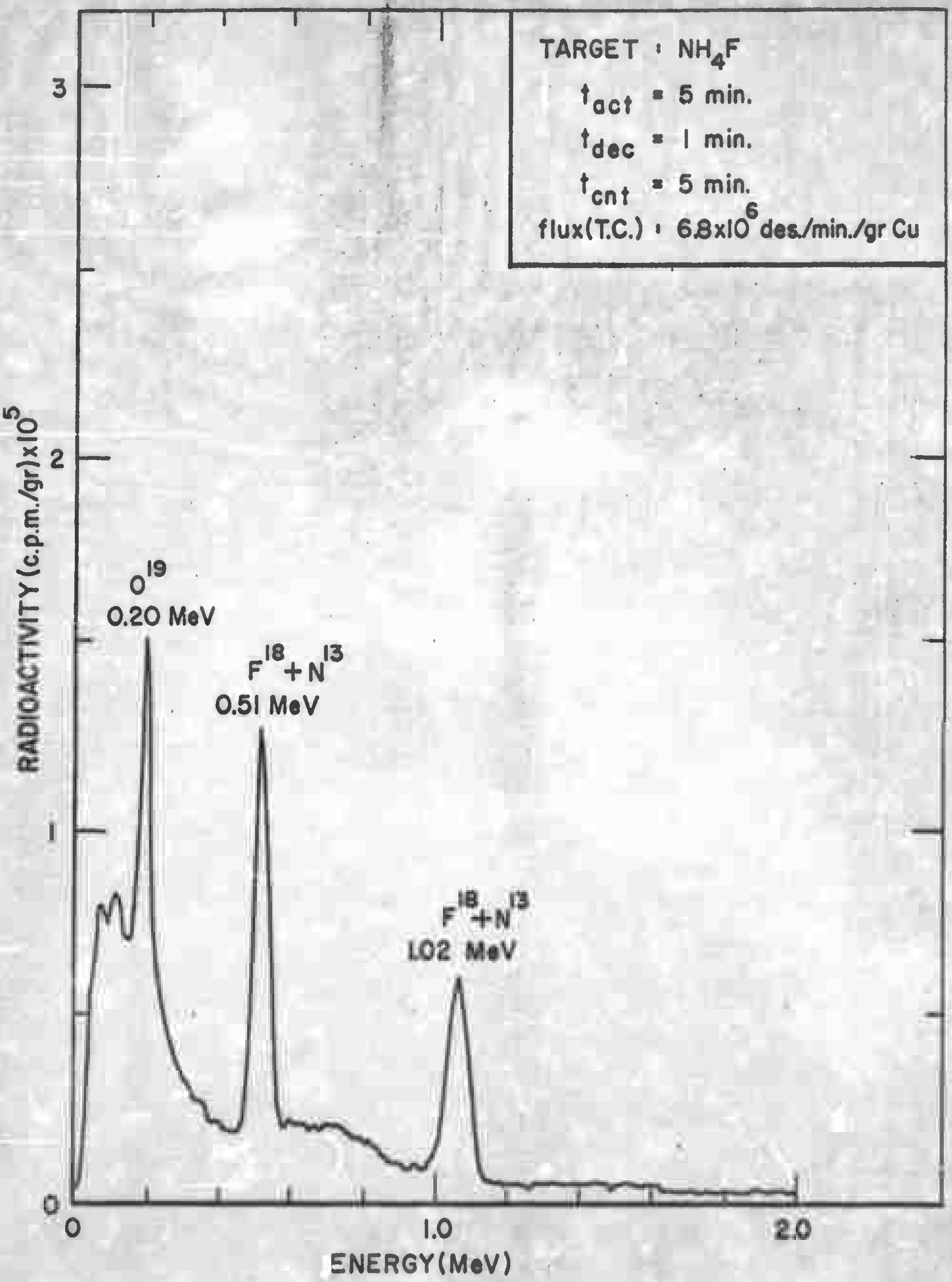

TARGET : NH_4F
t_{act} = 1.5 min.
t_{dec} = 29 sec.
t_{cnt} = 1.5 min.
flux(T.C.) = 6.9×10^6 des./min./gr. Cu
x10
O^{19} 0.20 MeV
$F^{18} + N^{13}$ 0.51 MeV
$F^{18} + N^{13}$ 1.02 MeV
O^{19} 1.36 MeV
O^{19} 1.56 MeV
RADIOACTIVITY (c.p.m./gr.) $\times 10^5$
ENERGY (MeV)
0
1
2
3
4
0
1.0
2.0

FIGURE I-F



TARGET : NH_4F
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) : 6.8×10^6 des./min./gr Cu
RADIOACTIVITY (c.p.m./gr) $\times 10^5$
O^{19}
0.20 MeV
$F^{18} + N^{13}$
0.51 MeV
$F^{18} + N^{13}$
1.02 MeV
0
1
2
3
0
1.0
2.0
ENERGY (MeV)

FIGURE II-F

TABLE II-F

PEAKS OBSERVED IN FIGURES I-F and II-F

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-F	0.20	$F^{19}(n,p)O^{19}$	29 s	
	0.51	$F^{19}(n,2n)F^{18}$	110 m	
	1.02	$F^{19}(n,2n)F^{18}$	110 m	0.51 Mev coincidence sum peak
	1.36	$F^{19}(n,p)O^{19}$	29 s	
	1.56	$F^{19}(n,p)O^{19}$	29 s	sum peak (1.36 Mev + 0.2 Mev)
II-F	0.20	$F^{19}(n,p)O^{19}$	29 s	
	C.51	$F^{19}(n,2n)F^{18}$	110 m	
	1.02	$F^{19}(n,2n)F^{18}$	110 m	0.51 Mev coincidence sum peak

NOTE: The $F^{19}(n,\alpha)N^{16}$ reaction will be discussed at the end of Part II

TABLE III-F

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.21	1.5 m	29 s	1.5 m	375	0.96
0.51	5 m	1 m	5 m	340 (1)	0.68
0.20	5 m	1 m	5 m	266	1.4

(1) The contribution of nitrogen present in NH_4F to the 0.51 Mev peak is equal to 132 counts. This value has been subtracted from the N^{13} + F^{18} activity.

TABLE IF-F

POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for fluorine from any other element.

For other positron emitting radioisotopes than F^{18}, see Section I, Appendix II.

GADOLINIUM

TABLE I - Gd

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Gd^{152}	0.20%	$Gd^{152}(n,p)Eu^{152m}$	96 m	0.02, 0.09, IT 0.04
		$Gd^{152}(n,p)Eu^{152m}$	9.3 h	0.12, 0.84, 0.96, β+
		$Gd^{152}(n,p)Eu^{152}$	12.4 y	0.12, 0.34, β+
		$Ge^{152}(n,2n)Gd^{151}$	120 d	0.022, 0.175, 0.08, 0.035
Gd^{154}	2.15%	$Gd^{154}(n,p)Eu^{154}$	16 y	1.28, 0.123, 0.72, 0.25, 1.61
		$Gd^{154}(n,\alpha)Sm^{151}$	90 y	0.022
		$Gd^{154}(n,2n)Gd^{153}$	240 d	0.097, 0.103 0.070
Gd^{155}	14.73%	$Gd^{155}(n,p)Eu^{155}$	1.8 y	0.087, 0.015, 0.137
Gd^{156}	20.47%	$Gd^{156}(n,p)Eu^{156}$	15.2 d	0.089, 1.23, 0.20, 2.19
		$Gd^{156}(n,\alpha)Sm^{153}$	47 h	0.103, 0.07, 0.02, 0.64
Gd^{157}	15.68%	$Gd^{157}(n,p)Eu^{157}$	15.2 h	0.065, 0.41, 0.16, 0.97
Gd^{158}	24.87%	$Gd^{158}(n,p)Eu^{158}$	46 m	0.080, 0.95, 0.89, 0.18, 2.8

TABLE I - Gd (Cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
		$Gd^{158}(n,\alpha)Sm^{155}$	22 m	0.10, 0.25, 0.14
Gd^{160}	21.90%	$Gd^{160}(n,p)Eu^{160}$	~2.5 m	
		$Gd^{160}(n,\alpha)Sm^{157}$	0.5 m	0.57
		$Gd^{160}(n,2n)Gd^{159}$	18 h	0.058, 0.36

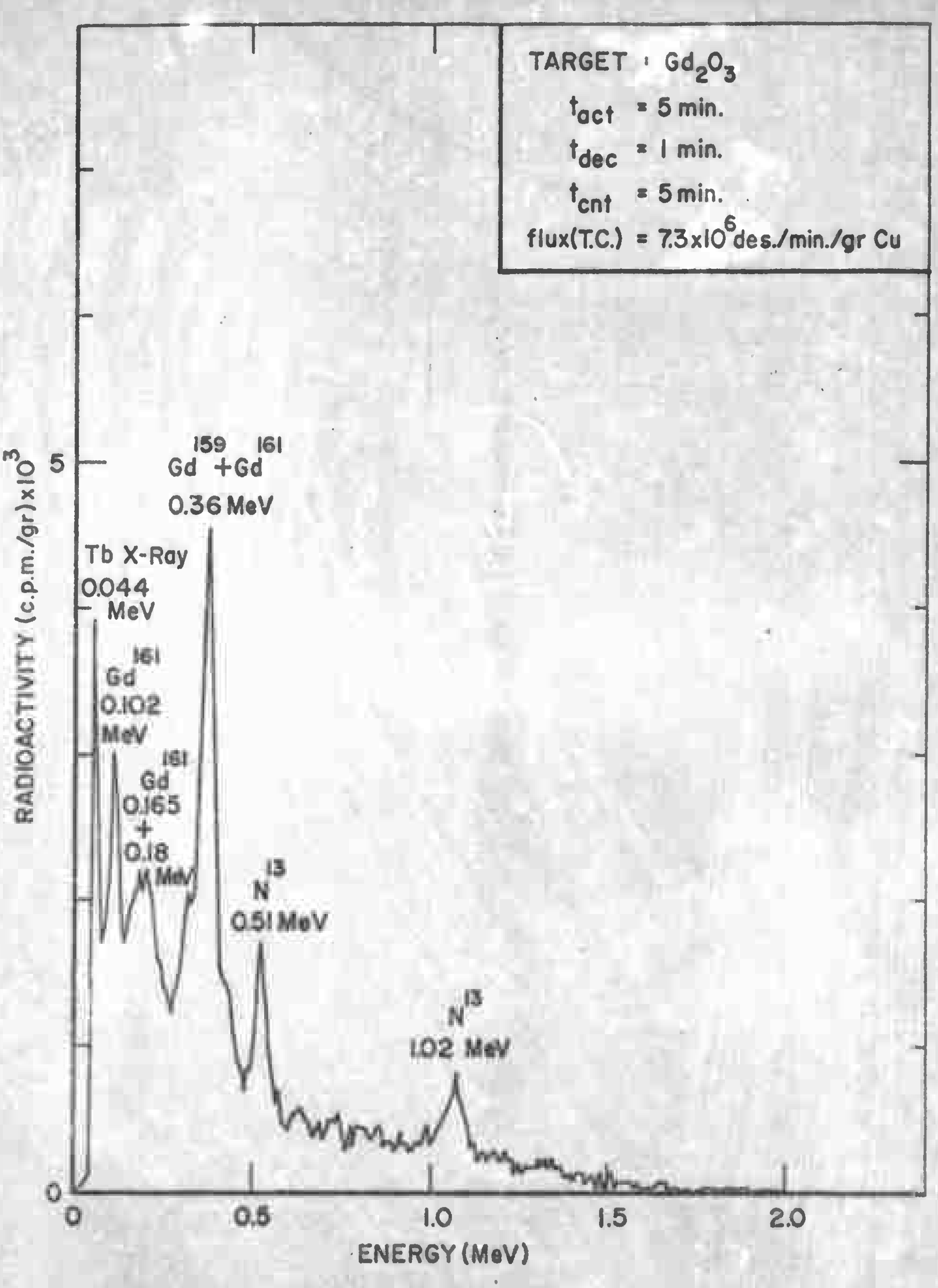

TARGET : Gd_2O_3
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) = 7.3×10^6 des./min./gr Cu
RADIOACTIVITY (c.p.m./gr) $\times10^3$
$Gd^{159}+Gd^{161}$
0.36 MeV
Tb X-Ray
0.044 MeV
Gd^{161}
0.102 MeV
Gd^{161}
0.165 + 0.18 MeV
N^{13}
0.51 MeV
N^{13}
1.02 MeV
0
5
0.5
1.0
1.5
2.0
ENERGY (MeV)

FIGURE I-Gd

TABLE II-Gd

PEAKS OBSERVED IN FIGURE I-Gd

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Gd	0.044			Tb x-ray
	0.102	$Gd^{160}(n,\gamma)Gd^{161}$	3.7 m	
	0.165 + 0.18	$Gd^{160}(n,\gamma)Gd^{161}$	3.7 m	
	0.36	$Gd^{160}(n,\gamma)Gd^{161}$	3.7 m	
		$Gd^{160}(n,2n)Gd^{159}$	18 h	

TABLE III-Gd

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.36	5 m	1 m	5 m	12	14

TABLE IV-Gd

POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for gadolinium from any other element.

GALLIUM

TABLE I - Ga

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Ga^{69}	60.40%	$Ga^{69}(n,p)Zn^{69m}$	14 h	IT 0.44
		↓		
		$Ga^{69}(n,p)Zn^{69}$	55 m	
		$Ga^{69}(n,\alpha)Cu^{66}$	5.1 m	1.04, 0.83
		$Ga^{69}(n,2n)Ga^{68}$	68 m	1.08, 0.81, 1.88 β+
Ga^{71}	39.60%	$Ga^{71}(n,p)Zn^{71m}$	3.9 h	0.39, 0.49, 0.61
		↓		
		$Ga^{71}(n,p)Zn^{71}$	2.5 m	0.51
		$Ga^{71}(n,\alpha)Cu^{68}$	30 s	1.08, 0.81, 1.88, 1.24
		$Ga^{71}(n,2n)Ga^{70}$	21 m	1.04 0.17

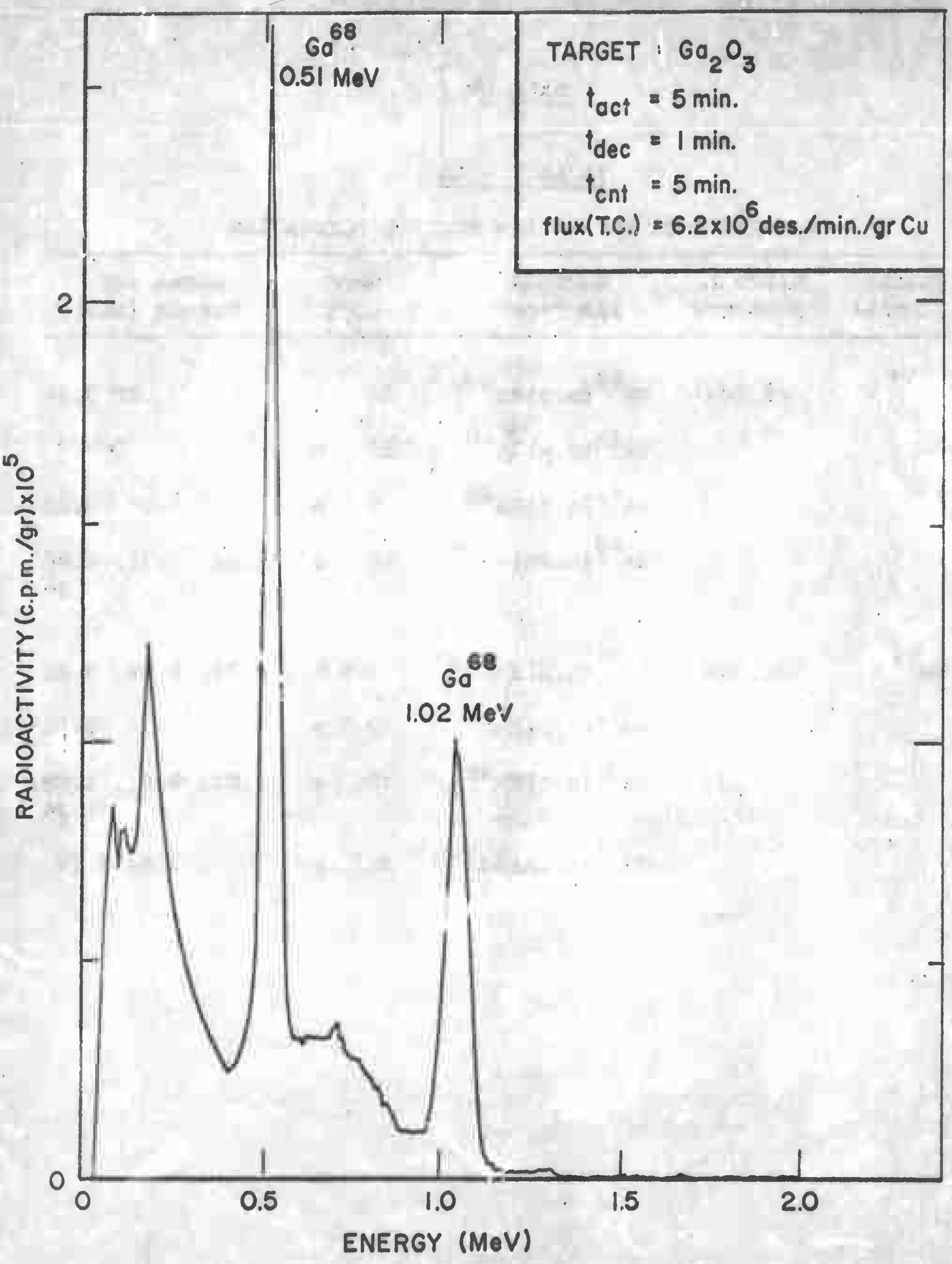

TARGET : Ga_2O_3
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) = 6.2×10^6 des./min./gr Cu
Ga^{68}
0.51 MeV
Ga^{68}
1.02 MeV
RADIOACTIVITY (c.p.m./gr)$\times 10^5$
0
2
0
0.5
1.0
1.5
2.0
ENERGY (MeV)

FIGURE I-Ga

TABLE II-Ga

PEAKS OBSERVED IN FIGURE I-Ga

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Ga	0.51	$Ga^{69}(n,2n)Ga^{68}$	68 m	
	1.02	$Ga^{69}(n,2n)Ga^{68}$	68 m	0.51 Mev coincidence sum peak

REMARK: Cu^{68} ($T_{1/2}$ = 30 sec) not detected for 1.5 min irradiation, 30 sec decay and 1.5 min counting time.

TABLE III-Ga

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.51	5 m	1 m	5 m	917	0.18

TABLE IV-Ga

POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for gallium from any other element.

For other positron emitting radioisotopes than Ga^{68}, see Section I, Appendix II.

GERMANIUM

TABLE I - Ge

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Ge^{70}	20.52%	$Ge^{70}(n,p)Ga^{70}$	21 m	1.04, 0.17
		$Ge^{70}(n,2n)Ge^{69}$	40 h	1.12, 0.58, 0.88, 0.09, 2.0, β+
Ge^{72}	27.43%	$Ge^{72}(n,p)Ga^{72m}$	0.04s	IT 0.10
		$Ge^{72}(n,p)Ga^{72}$	14.1 h	0.84, 0.69, 0.11, 2.82
		$Ge^{72}(n,\alpha)Zn^{69m}$	14 h	IT 0.44
		$Ge^{72}(n,\alpha)Zn^{69}$	55 m	
		$Ge^{72}(n,2n)Ge^{71m}$	0.02s	0.175, IT 0.023
		$Ge^{72}(n,2n)Ge^{71}$	11 d	
Ge^{73}	7.76%	$Ge^{73}(n,p)Ga^{73}$	4.8 h	0.30, 0.74,0.054, 0.014
		$Ge^{73}(n,n')Ge^{73m}$	0.53s	IT 0.054
Ge^{74}	36.54%	$Ge^{74}(n,p)Ga^{74}$	8 m	0.60, 2.35, 0.38, 3.4
		$Ge^{74}(n,\alpha)Zn^{71m}$	3.9 h	0.39, 0.49, 0.61
		$Ge^{74}(n,\alpha)Zn^{71}$	2.5 m	0.51
		$Ge^{74}(n,2n)Ge^{73m}$	0.53s	IT 0.054

GERMANIUM

TABLE I - Ge (Cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE		GAMMA RAY ENERGY (Mev)
Ge^{76}	7.76%	$Ge^{76}(n,p)Ga^{76}$	32	s	0.57, 0.96, 1.12
		$Ge^{76}(n,2n)Ge^{75m}$	49	s	IT 0.14
		$Ge^{76}(n,2n)Ge^{75}$	82	m	0.27, 0.07, 0.63

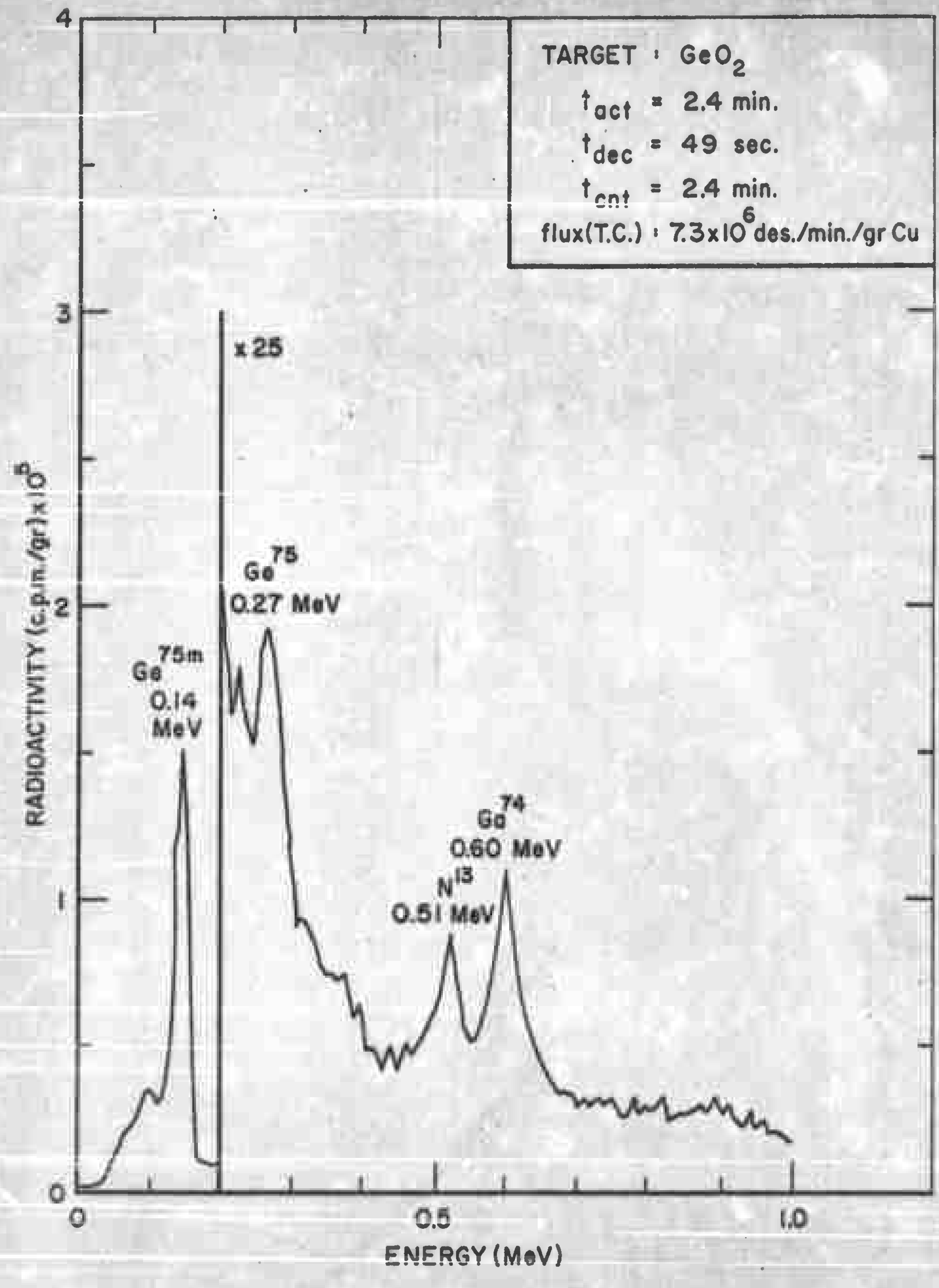

TARGET : GeO_2
t_{act} = 2.4 min.
t_{dec} = 49 sec.
t_{cnt} = 2.4 min.
flux(T.C.) : 7.3×10^6 des./min./gr Cu
x 25
Ge^{75}
0.27 MeV
Ge^{75m}
0.14
MeV
Ge^{74}
0.60 MeV
N^{13}
0.51 MeV
RADIOACTIVITY (c.p.m./gr) x 10^5
ENERGY (MeV)
0
1
2
3
4
0.5
1.0

FIGURE I-Ge

TABLE II-Ge

PEAKS OBSERVED IN FIGURE I-Ge

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Ge	0.14	$Ge^{76}(n,2n)Ge^{75m}$	49 s	
	0.27	$Ge^{76}(n,2n)Ge^{75}$	82 m	
	0.60	$Ge^{74}(n,p)Ga^{74}$	8 m	

NOTE: A 5 minute irradiation does not bring any new gamma ray peaks.

TABLE III-Ge

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.14	2.4 m	49 s	2.4 m	198	0.38
0.14	5 m	1 m	5 m	294	0.46
0.27	5 m	1 m	5 m	34	3.4
0.60	5 m	1 m	5 m	34	5.8

TABLE IV-Ge

POSSIBLE INTERFERING REACTIONS

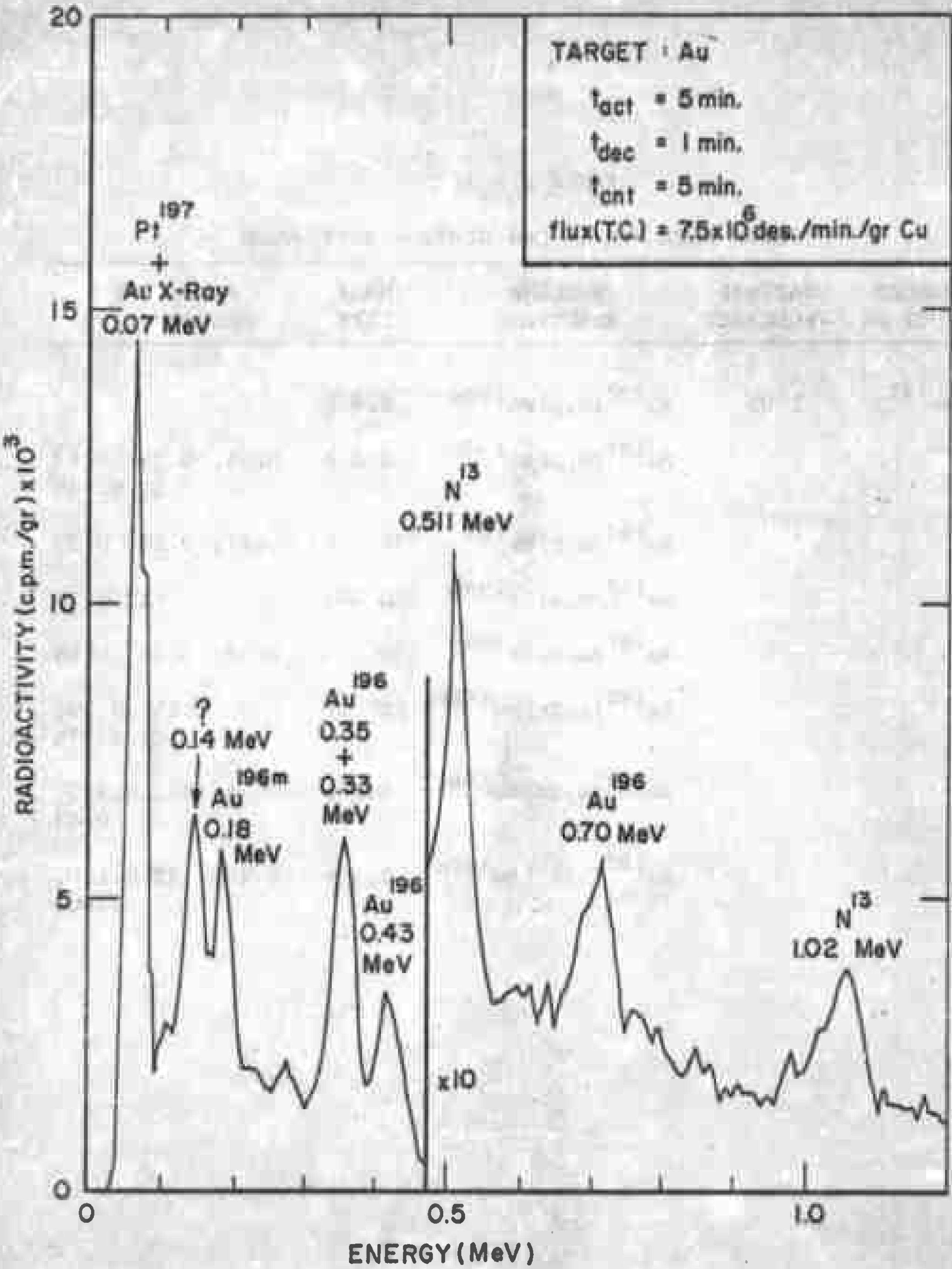
GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.14	Arsenic	$As^{75}(n,p)Ge^{75m}$	

GOLD

TABLE I - Au

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Au^{197}	100%	$Au^{197}(n,p)Pt^{197m}$	2.8 h	
		$Au^{197}(n,p)Pt^{197m}$	1.5 h	0.05, 0.28, 0.13 IT 0.346
		$Au^{197}(n,p)Pt^{197}$	20 h	0.077, 0.19, 0.27
		$Au^{197}(n,\alpha)Ir^{194m}$	0.05s	IT 0.10
		$Au^{197}(n,\alpha)Ir^{194m}$	19 h	0.33, 0.29, 0.65
		$Au^{197}(n,2n)Au^{196m}$	10 h	0.15, 0.19, IT 0.175
		$Au^{197}(n,2n)Au^{196}$	6.2 d	0.356, 0.333, 0.43
		$Au^{197}(n,n')Au^{197m}$	7.2 s	0.279, IT 0.130, 0.409



TARGET : Au
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) = 7.5×10^6 des./min./gr Cu
Pt^{197} + Au X-Ray 0.07 MeV
? 0.14 MeV
Au^{196m} 0.18 MeV
Au^{196} 0.35 + 0.33 MeV
Au^{196} 0.43 MeV
x10
N^{13} 0.511 MeV
Au^{196} 0.70 MeV
N^{13} 1.02 MeV
RADIOACTIVITY (c.p.m./gr) x 10^3
ENERGY (MeV)
0
5
10
15
20
0.5
1.0

FIGURE I-Au

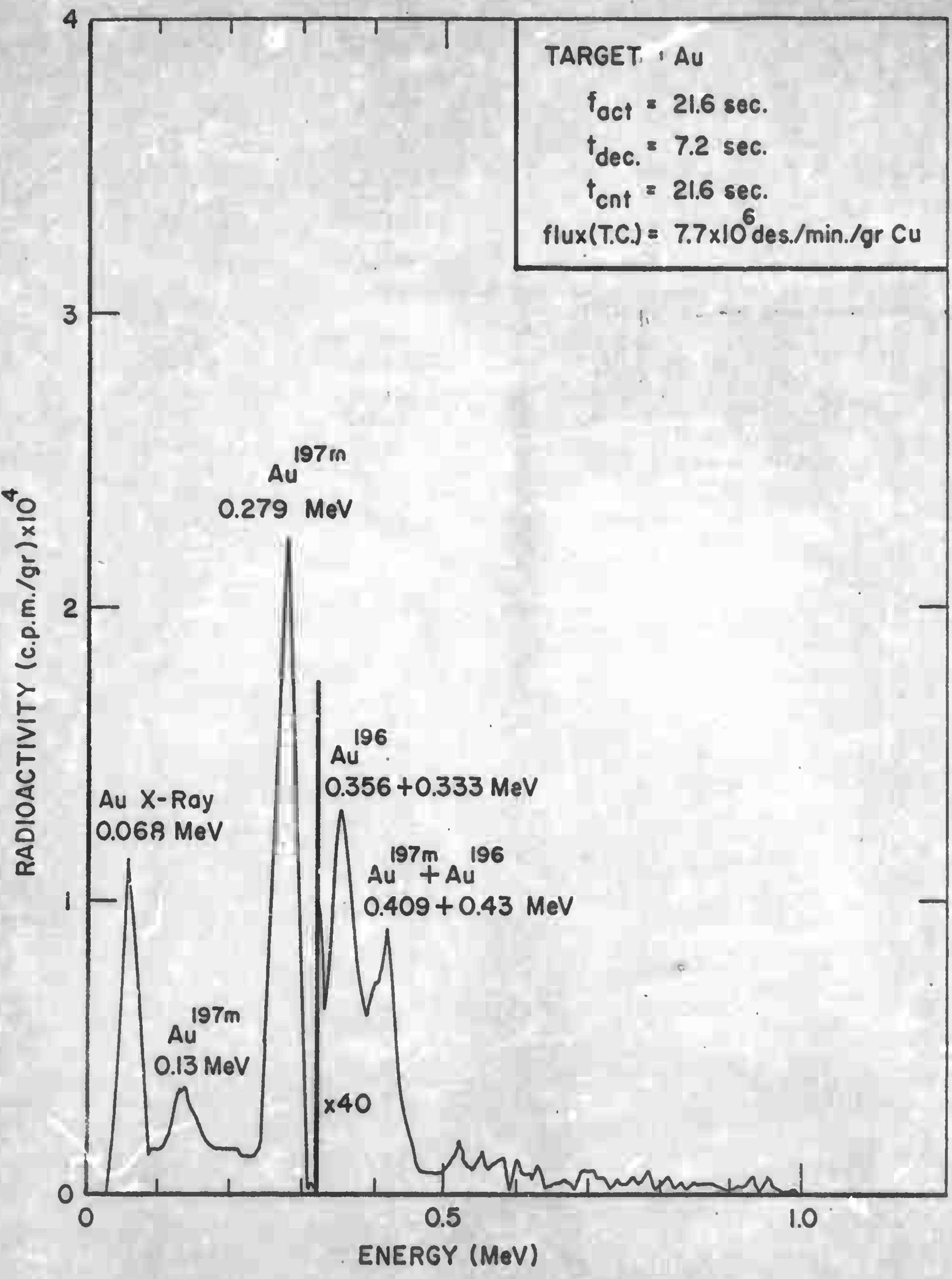

TARGET : Au
t_{act} = 21.6 sec.
$t_{dec.}$ = 7.2 sec.
t_{cnt} = 21.6 sec.
flux(T.C.) = 7.7x10^6 des./min./gr Cu
Au^{197m}
0.279 MeV
Au^{196}
0.356 + 0.333 MeV
Au X-Ray
0.068 MeV
Au^{197m} + Au^{196}
0.409 + 0.43 MeV
Au^{197m}
0.13 MeV
x40
RADIOACTIVITY (c.p.m./gr) x10^4
ENERGY (MeV)
0
0.5
1.0
1
2
3
4

FIGURE II-Au

TABLE II-Au

PEAKS OBSERVED IN FIGURES I-II Au

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Au	0.07 + 0.077	$Au^{197}(n,p)Pt^{197}$	20 h	Also Au x-ray
	0.14			$T_{1/2} \sim 20$ h
	0.18	$Au^{197}(n,2n)Au^{196m}$	10 h	
	0.356 + 0.331	$Au^{197}(n,2n)Au^{196}$	6.2d	
	0.43	$Au^{197}(n,2n)Au^{196}$	6.2d	
	~0.70	$Au^{197}(n,2n)Au^{196}$	6.2d	Sum peak of 0.356 + 0.331
II-Au	0.068			Au x-ray
	0.13	$Au^{197}(n,n')Au^{197m}$	7.2s	
	0.279	$Au^{197}(n,n')Au^{197m}$	7.2s	
	0.356 + 0.333	$Au^{197}(n,2n)Au^{196}$	6.2d	
	0.409 + 0.43	$Au^{197}(n,2n)Au^{196}$	6.2d	
		$Au^{197}(n,n')Au^{197m}$	7.2s	

TABLE III-Au

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.356 + 0.331	5 m	1 m	5 m	16	7.0
0.43	5 m	1 m	5 m	7	19
0.279	21,6s	7.2s	21.6s	60	0.60

TABLE IV-Au

POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for gold from any other element.

HAFNIUM

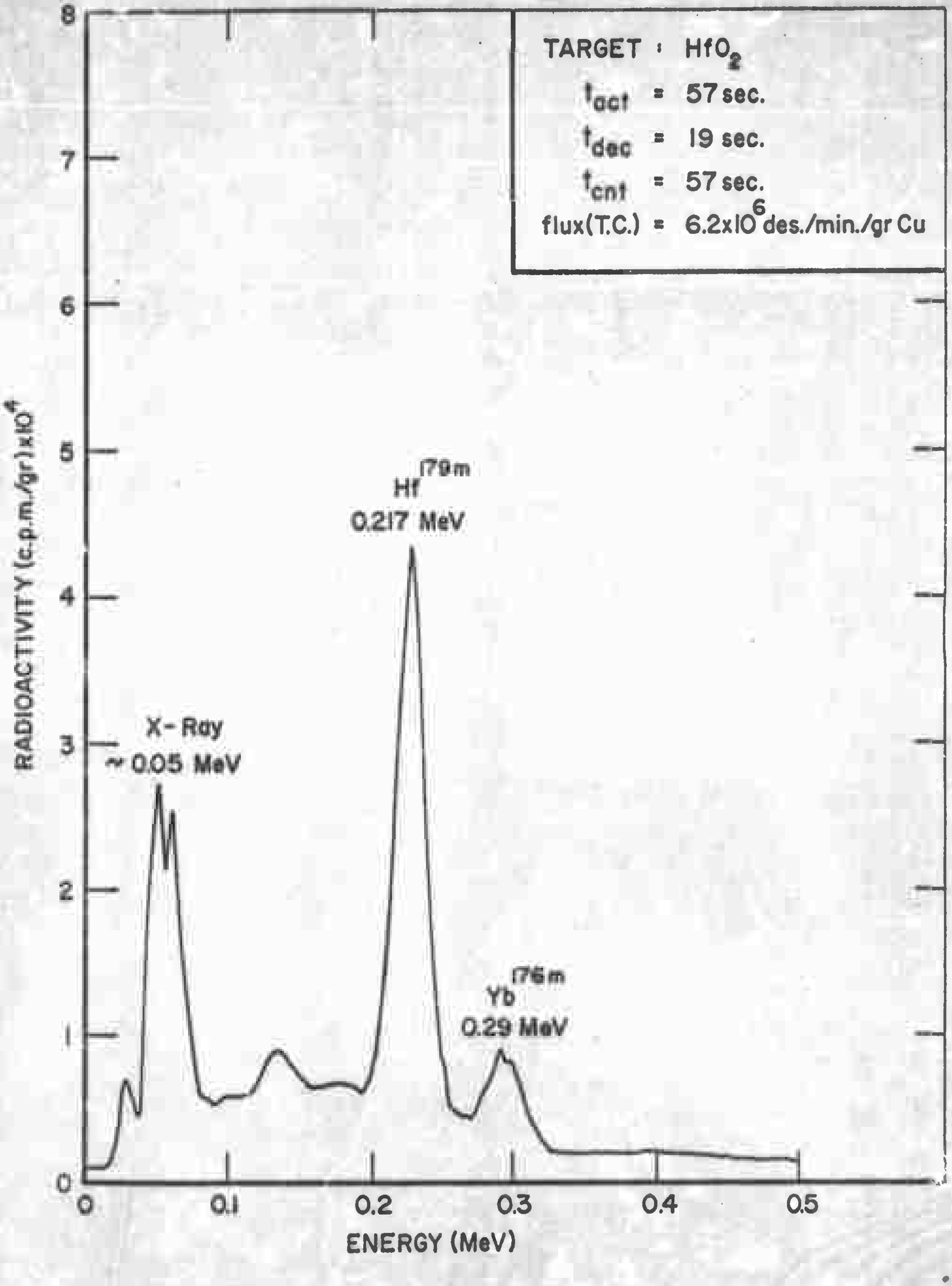
TABLE I - Hf

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Hf^{174}	0.18%	$Hf^{174}(n,p)Lu^{174m}$	75 μs	IT 0.133
		$Hf^{174}(n,p)Lu^{174m}$	165 d	0.044, 0.99, IT 0.059
		$Hf^{174}(n,p)Lu^{174}$	300 d	0.077, 1.2
		$Hf^{174}(n,2n)Hf^{173}$	24 h	0.140, 0.124, 0.135, 0.163, 1.2
Hf^{176}	5.2%	$Hf^{176}(n,p)Lu^{176m}$	3.7h	0.088
		$Hf^{176}(n,2n)Hf^{175}$	70 d	0.343, 0.089, 0.113, 0.432
Hf^{177}	18.50%	$Hf^{177}(n,p)Lu^{177m}$	155 d	IT 0.12, 0.055, 0.47
		$Hf^{177}(n,p)Lu^{177}$	6.8d	0.208, 0.113, 0.07, 0.32
		$Hf^{177}(n,\alpha)Yb^{174}$	0.001s	0.27, 0.18, 0.076, IT 1.00 1.28
Hf^{178}	27.14%	$Hf^{178}(n,p)Lu^{178m}$	30 m	0.089, 0.093, 0.43
		$Hf^{178}(n,p)Lu^{178}$	5 m	0.33, 0.089, 0.093, 0.43
		$Hf^{178}(n,\alpha)Yb^{175m}$	0.067s	IT 0.50

TABLE I - Hf (Cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
		$Hf^{178}(n,\alpha)Yb^{175}$	4.2 d	0.40, 0.11, 0.28, 0.14, 0.25
		$Hf^{178}(n,n')Hf^{178m}$	4.3 s	0.093, 0.43, IT 0.089
Hf^{179}	13.95%	$Hf^{179}(n,p)Lu^{179}$	4.6 h	0.22, 0.05
		$Hf^{179}(n,\alpha)Yb^{176m}$	12 s	0.29, 0.39, IT 0.19
		$Hf^{179}(n,2n)Hf^{178m}$	4.3 s	0.093, 0.43, IT 0.089
		$Hf^{179}(n,n')Hf^{179m}$	19 s	0.217, IT 0.161
Hf^{180}	35.24%	$Hf^{180}(n,p)Lu^{180}$	2.5 m	
		$Hf^{180}(n,\alpha)Yb^{177m}$	6.5 s	0.10, IT 0.23
		$Hf^{180}(n,\alpha)Yb^{177}$	1.9 h	0.15, 0.12, 0.11, 0.14, 1.24
		$Hf^{180}(n,2n)Hf^{179m}$	19 s	IT 0.161, 0.217
		$Hf^{180}(n,n')Hf^{180m}$	5.5 h	0.093, 0.44, IT 0.058, 0.50



TARGET : HfO_2
t_{act} = 57 sec.
t_{dec} = 19 sec.
t_{cnt} = 57 sec.
flux(T.C.) = 6.2×10^6 des./min./gr Cu
X - Ray
~ 0.05 MeV
Hf^{179m}
0.217 MeV
Yb^{176m}
0.29 MeV
RADIOACTIVITY (c.p.m./gr) x10^4
ENERGY (MeV)
0
1
2
3
4
5
6
7
8
0.1
0.2
0.3
0.4
0.5

FIGURE I-Hf

TABLE II-Hf

PEAKS OBSERVED IN FIGURE I-Hf

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Hf	0.217	$Hf^{180}(n,2n)Hf^{179m}$	19 s	(1)
		$Hf^{179}(n,n')Hf^{179m}$	19 s	
	0.29	$Hf^{179}(n,\alpha)Yb^{176m}$	12 s	
	~0.05			Hf x-ray

REMARKS: The decay curve on the 0.217 Mev photopeak shows a 19 second half life. This means that the activity due to Yb^{177m} ($T_{1/2}$ = 6.5 s) is negligible.

A five minute irradiation of hafnium does not show up other useful analytical gamma ray peaks.

A 10 second irradiation shows up a very low level of activity at 0.32 Mev and 0.43 Mev due to Hf^{178m} (T = 4.3 s).

TABLE III-Hf

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.217	57 s	19 s	57 s	171	1.0
0.29	57 s	19 s	57 s	20	6.9

TABLE IV-Hf

POSSIBLE INTERFERING REACTIONS

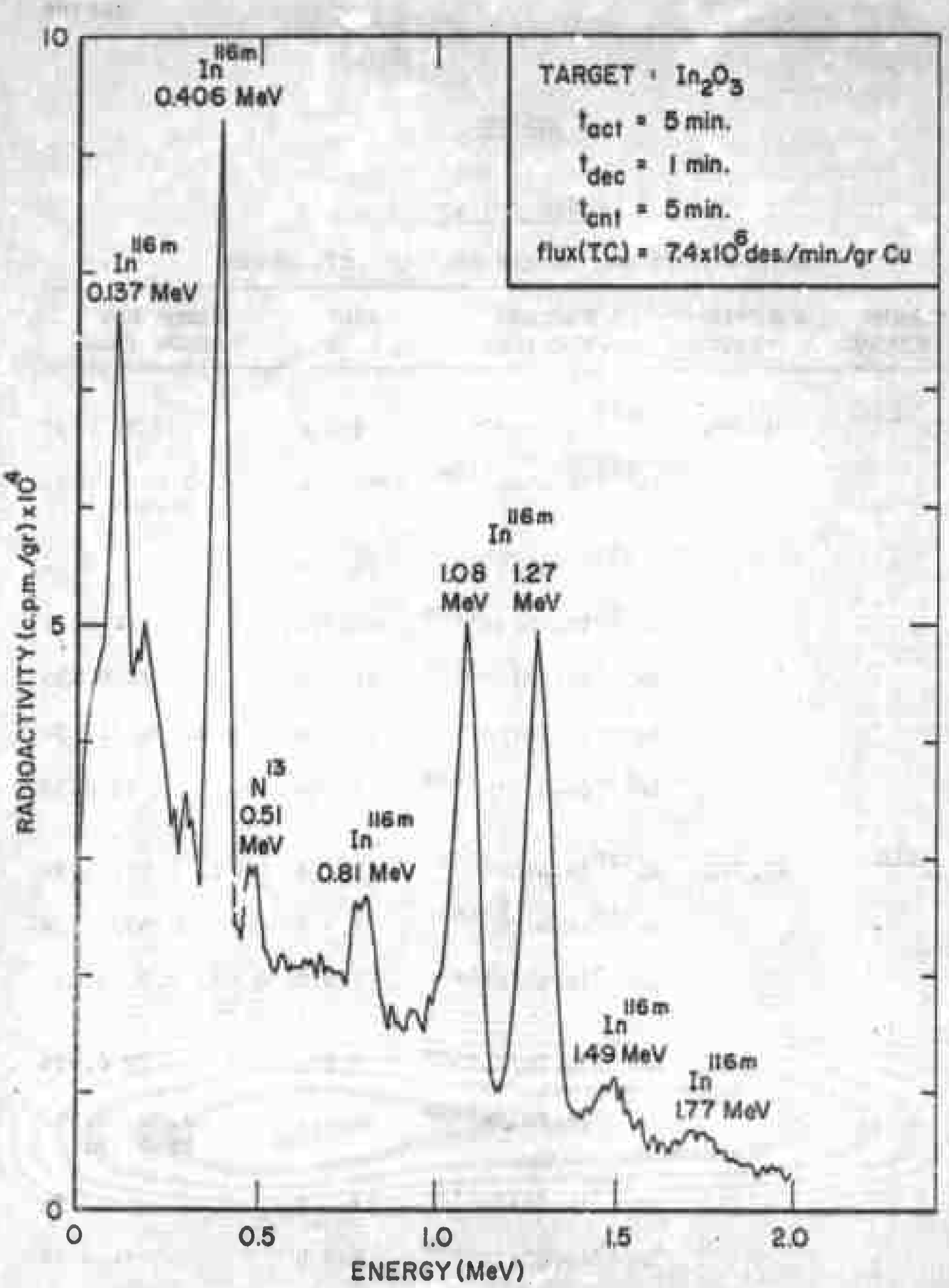
No detectable interferences could be derived for hafnium from any other element.

INDIUM

TABLE I - In

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
In^{113}	4.28%	$In^{113}(n,p)Cd^{113}$	14 y	IT 0.27
		$In^{113}(n,\alpha)Ag^{110m}$	260 d	0.66, 0.88, IT 0.12
		$In^{113}(n,\alpha)Ag^{110}$	24 s	0.66
		$In^{113}(n,2n)In^{112m}$	0.042s	IT 0.31
		$In^{113}(n,2n)In^{112m}$	21 m	IT 0.155
		$In^{113}(n,2n)In^{112}$	14 m	0.62, 0.71, $\beta+$
		$In^{113}(n,n')In^{113m}$	1.73h	IT 0.39
In^{115}	95.72%	$In^{115}(n,p)Cd^{115m}$	43 d	0.94, 0.17, 1.56
		$In^{115}(n,p)Cd^{115}$	2.3 d	0.52, 0.34
		$In^{115}(n,\alpha)Ag^{112}$	3.2 h	0.62, 1.4, 0.69, 3.28
		$In^{115}(n,2n)In^{114m}$	2.5 s	IT 0.150
		$In^{115}(n,2n)In^{114m}$	50 d	0.72, 0.56, IT 0.191
		$In^{115}(n,2n)In^{114}$	72 s	$\beta+$
		$In^{115}(n,n')In^{115m}$	4.4 h	IT 0.34



TARGET : In_2O_3
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) = 7.4×10^6 des./min./gr Cu
In^{116m} 0.406 MeV
In^{116m} 0.137 MeV
N^{13} 0.51 MeV
In^{116m} 0.81 MeV
In^{116m}
1.08 MeV
1.27 MeV
In^{116m} 1.49 MeV
In^{116m} 1.77 MeV
RADIOACTIVITY (c.p.m./gr) x 10^4
ENERGY (MeV)
10
5
0
0.5
1.0
1.5
2.0

FIGURE I-In

TABLE II-In

PEAKS OBSERVED IN FIGURE I-In

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-In	0.137	$In^{115}(n,\gamma)In^{116m}$	54 m	
	0.406	$In^{115}(n,\gamma)In^{116m}$	54 m	
	0.81	$In^{115}(n,\gamma)In^{116m}$	54 m	
	1.08	$In^{115}(n,\gamma)In^{116m}$	54 m	
	1.27	$In^{115}(n,\gamma)In^{116m}$	54 m	
	1.49	$In^{115}(n,\gamma)In^{116m}$	54 m	
	1.77	$In^{115}(n,\gamma)In^{116m}$	54 m	

TABLE III-In

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.137	5 m	1 m	5 m	71	2.0
0.406	5 m	1 m	5 m	250	0.30
1.08	5 m	1 m	5 m	240	0.41
1.27	5 m	1 m	5 m	252	0.40

REMARK: The activity induced will depend largely from the thermal neutron flux present at the sample.

TABLE IV-In

POSSIBLE INTERFERING REACTIONS

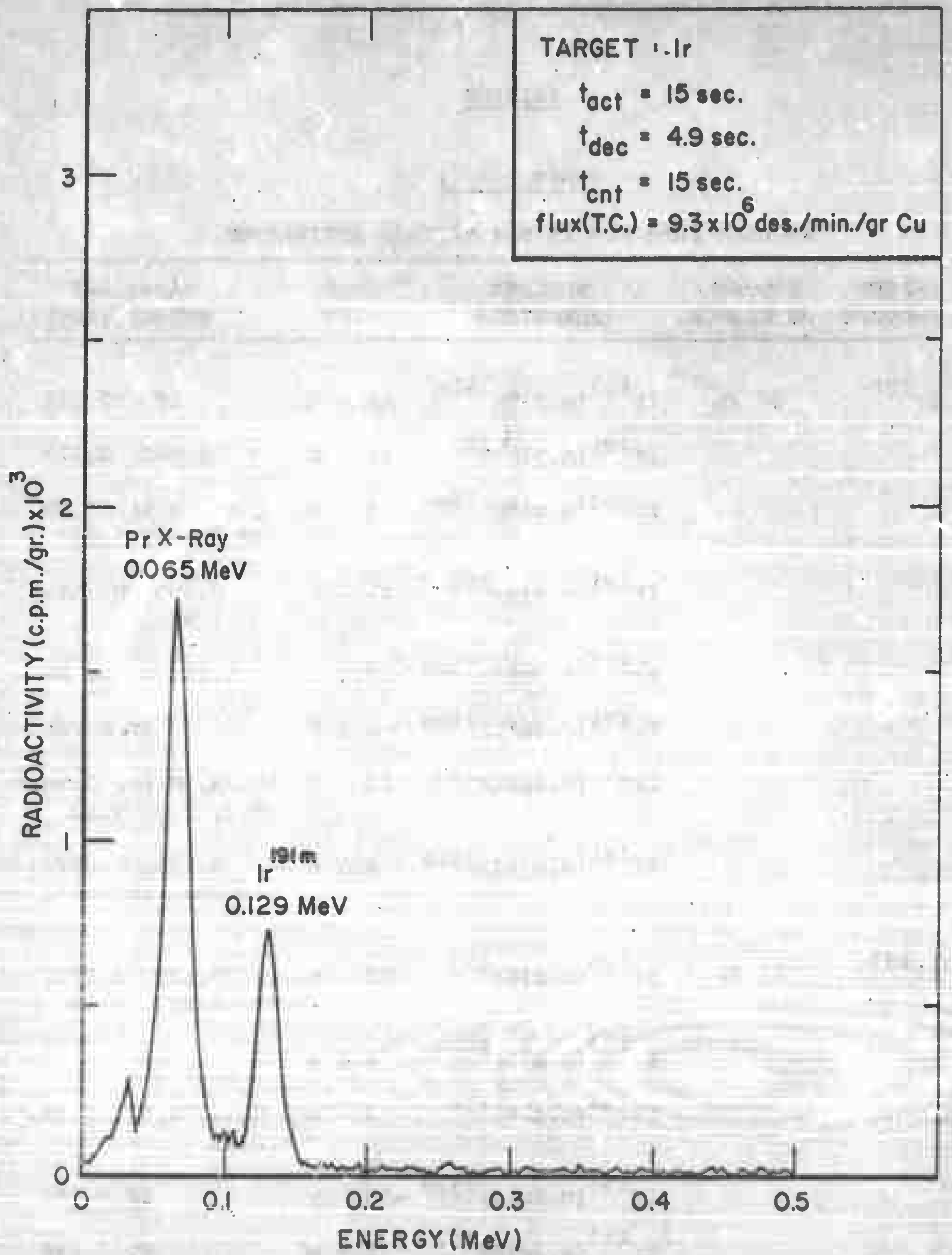
No detectable interferences could he derived for Indium from any other element.

IRIDIUM

TABLE I - Ir

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Ir^{191}	37.3%	$Ir^{191}(n,p)Os^{191m}$	14 h	IT 0.014
		$Ir^{191}(n,p)Os^{191}$	15 d	0.042, 0.129
		$Ir^{191}(n,\alpha)Re^{188m}$	19 m	0.06, 0.11, 0.09, IT 0.002, 0.02
		$Ir^{191}(n,\alpha)Re^{188}$	17 h	0.155, 0.218, 1.96
		$Ir^{191}(n,2n)Ir^{190m}$	3.2 h	0.19, 0.36, $\beta+$
		$Ir^{191}(n,2n)Ir^{190m}$	1.2 h	IT 0.026
		$Ir^{191}(n,2n)Ir^{190}$	12 d	0.19, 0.60, 0.56, 0.2, 1.3, 0.52
		$Ir^{191}(n,n')Ir^{191m}$	4.9 s	0.129, 0.047, 0.082, IT 0.042
Ir^{193}	62.7%	$Ir^{193}(n,p)Os^{193}$	32 h	0.139, 0.073, 0.107, 0.56
		$Ir^{193}(n,\alpha)Re^{190m}$	2.8 h	
		$Ir^{193}(n,\alpha)Re^{190}$	3 m	0.19, 0.57, 0.39, 0.83
		$Ir^{193}(n,2n)Ir^{192m}$	~600 y	IT 0.161
		$Ir^{193}(n,2n)Ir^{192m}$	1.4 m	IT 0.058
		$Ir^{193}(n,2n)Ir^{192}$	74 d	0.32,0.47,0.2,2.0
		$Ir^{193}(n,n')Ir^{193m}$	12 d	IT 0.08



TARGET : Ir
t_{act} = 15 sec.
t_{dec} = 4.9 sec.
t_{cnt} = 15 sec.
flux(T.C.) = 9.3×10^6 des./min./gr Cu
Pr X-Ray
0.065 MeV
Ir^{191m}
0.129 MeV
RADIOACTIVITY (c.p.m./gr.) x 10^3
ENERGY (MeV)

FIGURE I-Ir

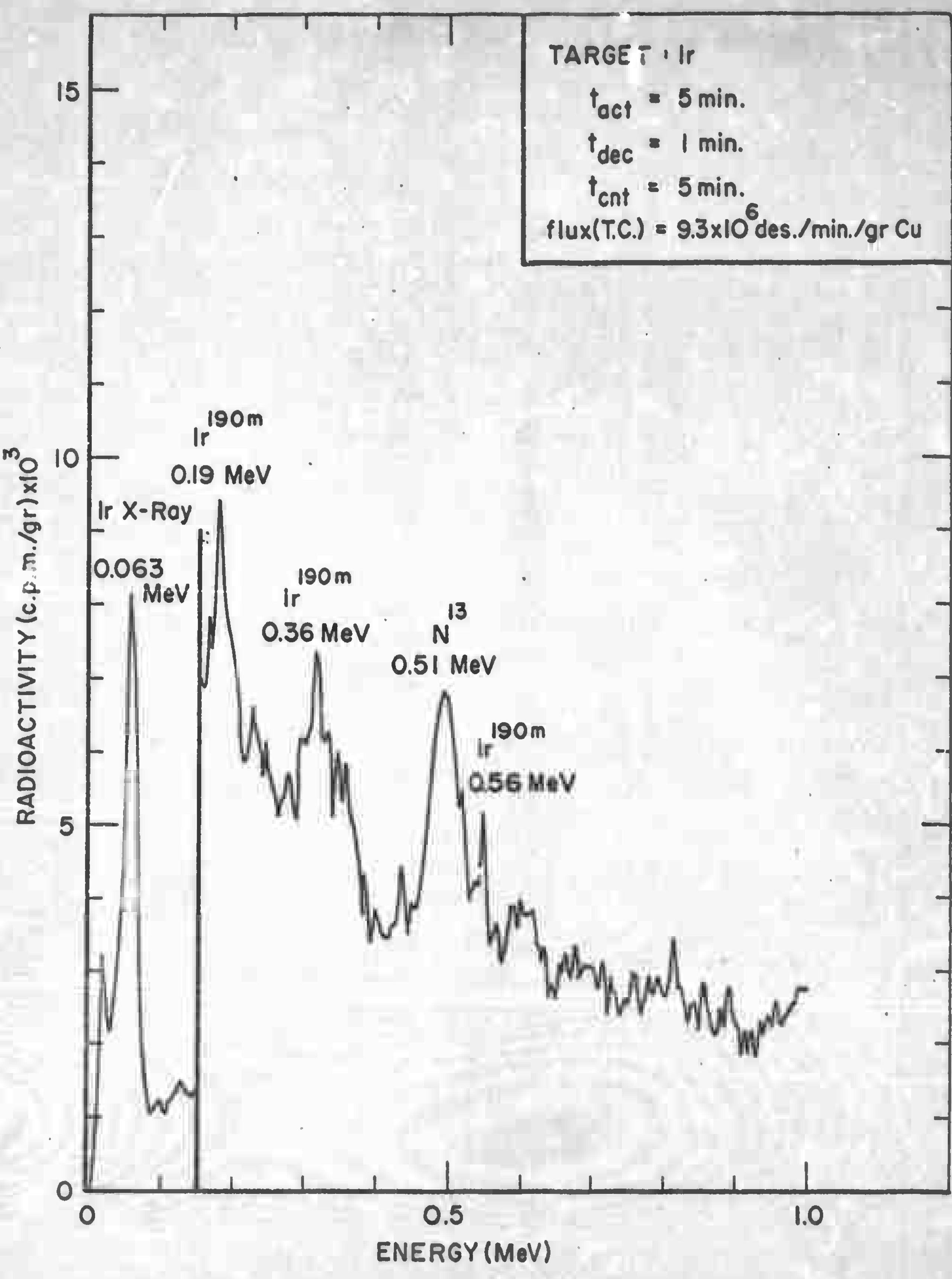

TARGET : Ir
t act = 5 min.
t dec = 1 min.
t cnt = 5 min.
flux(T.C.) = 9.3x10^6 des./min./gr Cu
RADIOACTIVITY (c.p.m./gr) x10^3
ENERGY (MeV)
0
0.5
1.0
5
10
15
Ir X-Ray
0.063 MeV
Ir^190m
0.19 MeV
Ir^190m
0.36 MeV
N^13
0.51 MeV
Ir^190m
0.56 MeV

FIGURE II-Ir

TABLE II-Ir

PEAKS OBSERVED IN FIGURE I-Ir

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Ir	0.065			Ir x-ray
	0.129	$Ir^{191}(n,n')Ir^{191m}$	4.9 s	
II-Ir	0.063			Ir x-ray
	0.19	$Ir^{191}(n,2n)Ir^{190m}$	3.2 h	
	0.36	$Ir^{191}(n,2n)Ir^{190m}$	3.2 h	
	0.56	$Ir^{191}(n,2n)Ir^{190m}$	3.2 h	

TABLE III-Ir

SENSITIVITIES FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.065	15 s	4.9s	15 s	5	14
0.129	15 s	4.9s	15 s	2	18
0.063	5 m	1 m	5 m	15	10

TABLE IV-Ir

POSSIBLE INTERFERING REACTIONS

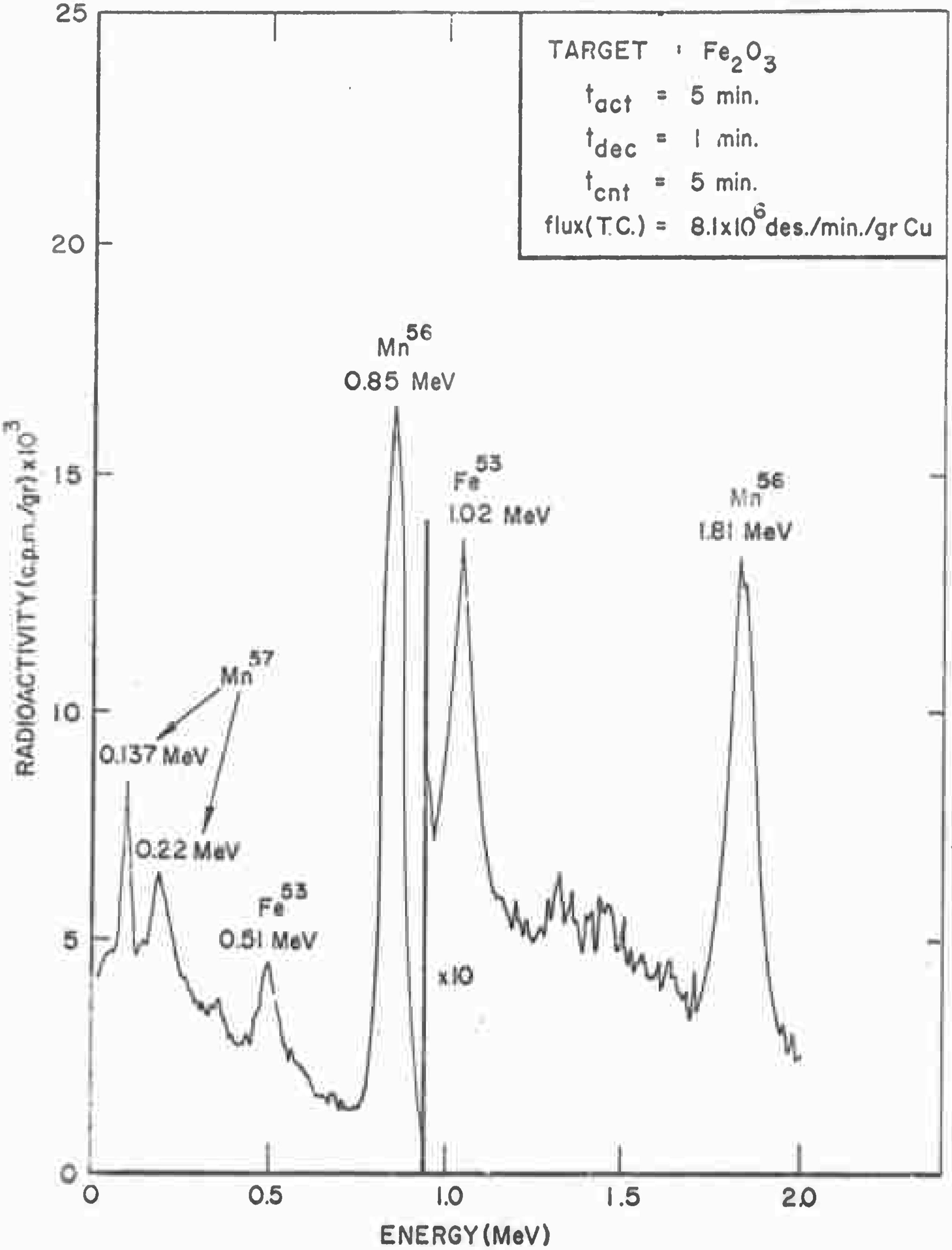
No detectable interferences could be derived for iridium from any other element.

IRON

TABLE I - Fe

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Fe^{54}	5.82%	$Fe^{54}(n,p)Mn^{54}$	303 d	0.84
		$Fe^{54}(n,\alpha)Cr^{51}$	27.8 d	0.32
		$Fe^{54}(n,2n)Fe^{53}$	8.5 m	0.38 $\beta+$
Fe^{56}	91.66%	$Fe^{56}(n,p)Mn^{56}$	2.58h	0.845, 1.81, 2.11
		$Fe^{56}(n,2n)Fe^{55}$	2.7 y	
Fe^{57}	2.19%	$Fe^{57}(n,p)Mn^{57}$	1.7 m	1.22, 0.014, 0.137, 0.22, 0.71
Fe^{58}	0.33%	$Fe^{58}(n,p)Mn^{58}$	1.1 m	
		$Fe^{58}(n,\alpha)Cr^{55}$	3.5 m	



TARGET : Fe_2O_3
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) = 8.1×10^6 des./min./gr Cu
Mn^{56}
0.85 MeV
Fe^{53}
1.02 MeV
Mn^{56}
1.81 MeV
Mn^{57}
0.137 MeV
0.22 MeV
Fe^{53}
0.51 MeV
x10
RADIOACTIVITY (c.p.m./gr) $\times 10^3$
ENERGY (MeV)
0
5
10
15
20
25
0.5
1.0
1.5
2.0

FIGURE I-Fe

TABLE II-Fe

PEAKS OBSERVED IN FIGURE I-Fe

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Fe	0.137	$Fe^{57}(n,p)Mn^{57}$	1.7 m	
	0.22	$Fe^{57}(n,p)Mn^{57}$	1.7 m	
	0.51	$Fe^{54}(n,2n)Fe^{53}$	8.5 m	
	1.02	$Fe^{54}(n,2n)Fe^{53}$	8.5 m	0.51 Mev coincidence sum peak
	0.845	$Fe^{56}(n,p)Mn^{56}$	2.58h	
	1.81	$Fe^{56}(n,p)Mn^{56}$	2.58h	

TABLE III-Fe

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.845	5 m	1 m	5 m	86	1.3

TABLE IV-Fe

POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.845	Cobalt	$Co^{59}(n,\alpha)Mn^{56}$	
	Manganese	$Mn^{55}(n,\gamma)Mn^{56}$	

LEAD

TABLE I-Pb

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Pb^{204}	1.48%	$Pb^{204}(n,p)Tl^{204}$	3.8 y	
		$Pb^{204}(n,\alpha)Hg^{201m}$	100μs	IT 0.53
		$Pb^{204}(n,2n)Pb^{203m}$	6.1 s	IT 0.83
		$Pb^{204}(n,2n)Pb^{203}$	52 h	0.28, 0.40, 0.68
		$Pb^{204}(n,n')Pb^{204m}$	67 m	0.29, 0.90, 0.375, IT 0.91
Pb^{206}	23.60%	$Pb^{206}(n,p)Tl^{206}$	4.3 m	
		$Pb^{206}(n,\alpha)Hg^{203}$	47 d	0.279
		$Pb^{206}(n,2n)Pb^{205m}$	0.004 s	0.99, IT 0.026
		$Pb^{206}(n,2n)Pb^{205}$	3×10^{7} y	
Pb^{207}	22.60%	$Pb^{207}(n,p)Tl^{207}$	4.78 m	0.89
		$Pb^{207}(n,n')Pb^{207m}$	0.8 s	0.57 , IT 1.06
Pb^{208}	52.30%	$Pb^{208}(n,p)Tl^{208}$	3.1 m	2.61, 0.58, 0.51, 0.23, 1.09
		$Pb^{208}(n,\alpha)Hg^{205}$	5.2 m	0.20
		$Pb^{208}(n,2n)Pb^{207m}$	0.8 s	0.57, IT 1.06

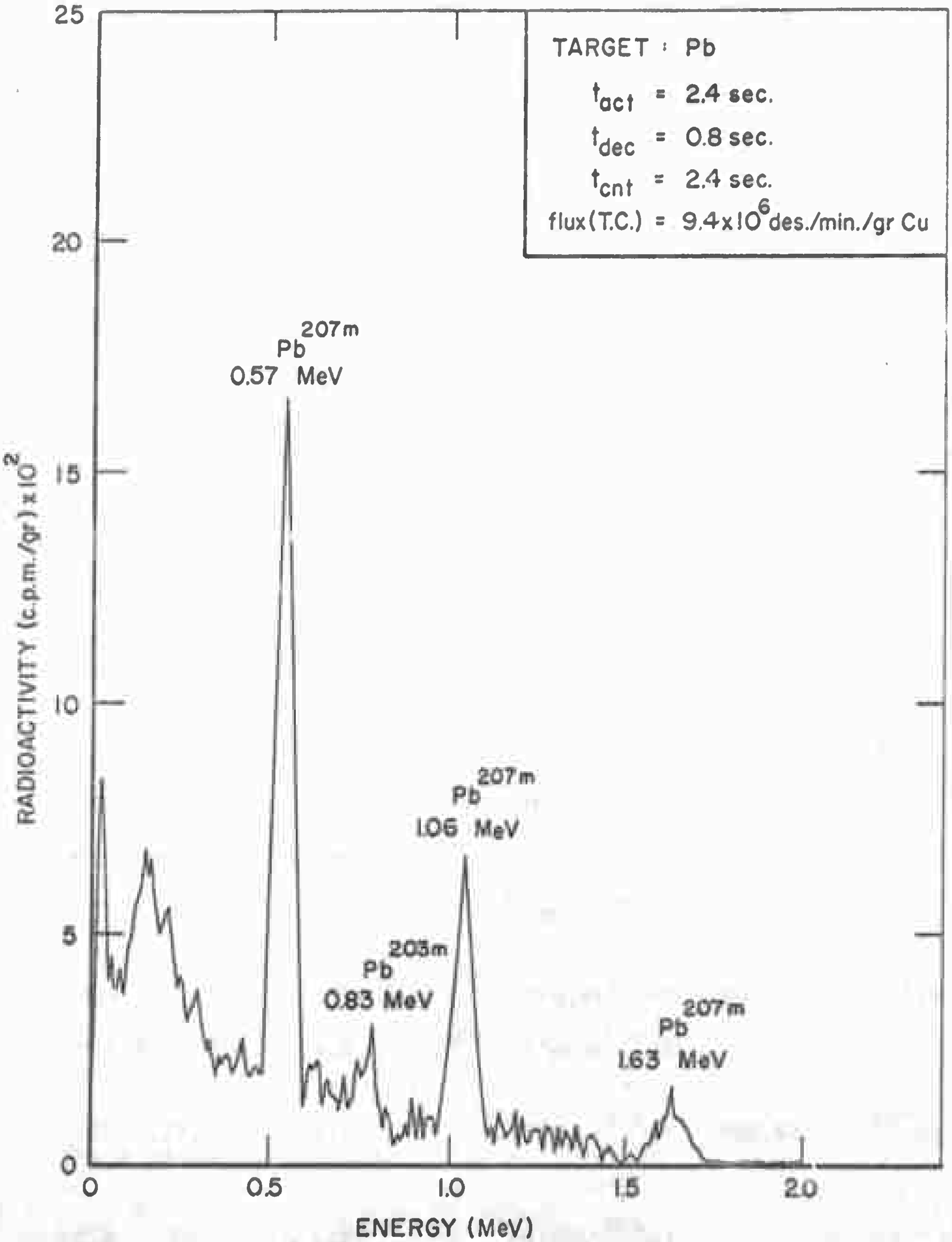
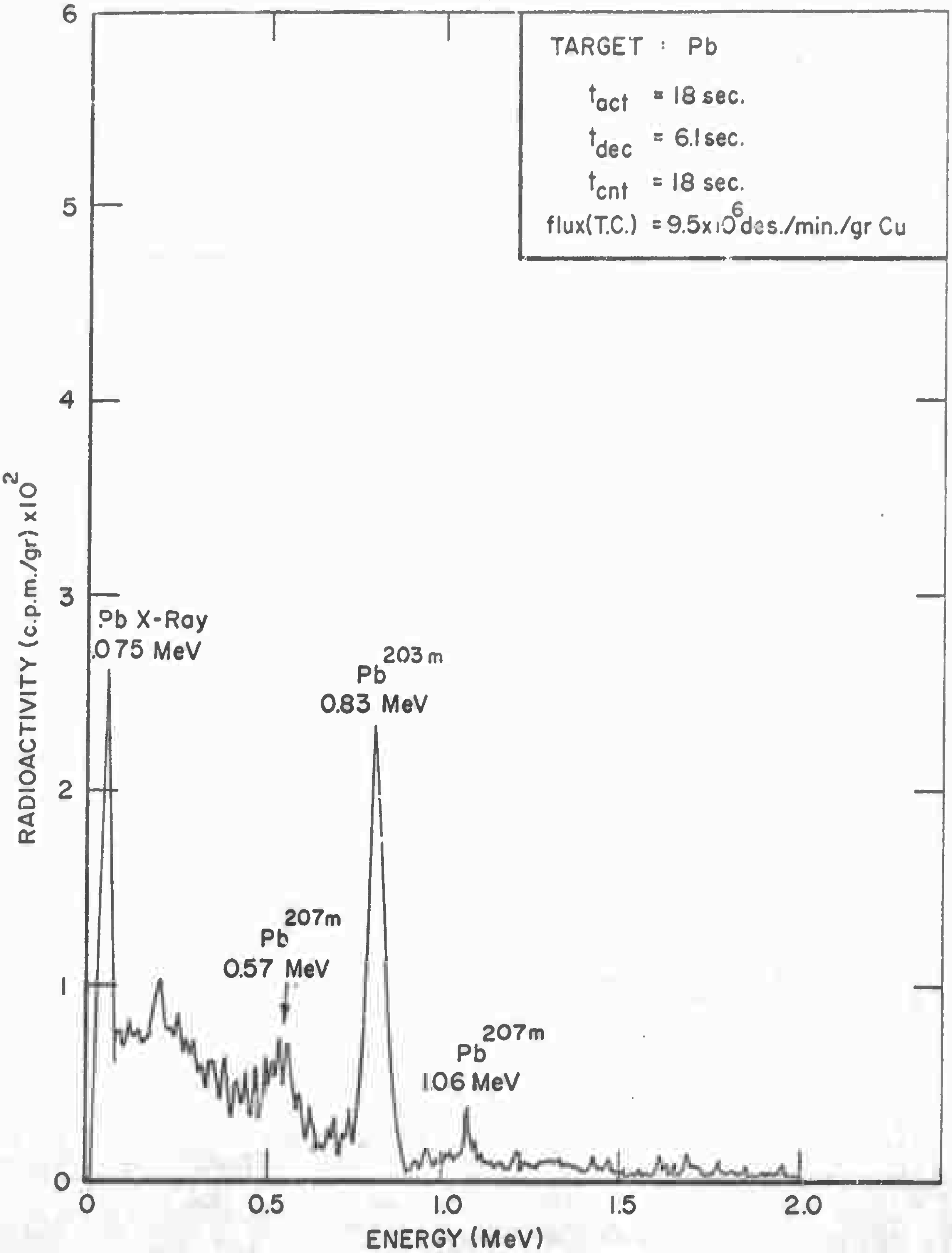

TARGET : Pb
t_{act} = 2.4 sec.
t_{dec} = 0.8 sec.
t_{cnt} = 2.4 sec.
flux(T.C.) = 9.4×10^6 des./min./gr Cu
Pb^{207m} 0.57 MeV
Pb^{207m} 1.06 MeV
Pb^{203m} 0.83 MeV
Pb^{207m} 1.63 MeV
RADIOACTIVITY (c.p.m./gr) $\times 10^2$
ENERGY (MeV)
0
5
10
15
20
25
0
0.5
1.0
1.5
2.0

FIGURE I-Pb



TARGET : Pb
t_{act} = 18 sec.
t_{dec} = 6.1 sec.
t_{cnt} = 18 sec.
flux(T.C.) = 9.5×10^6 des./min./gr Cu
Pb X-Ray
.075 MeV
Pb^{203m}
0.83 MeV
Pb^{207m}
0.57 MeV
Pb^{207m}
1.06 MeV
RADIOACTIVITY (c.p.m./gr) x10^2
ENERGY (MeV)
0
1
2
3
4
5
6
0
0.5
1.0
1.5
2.0

FIGURE II-Pb

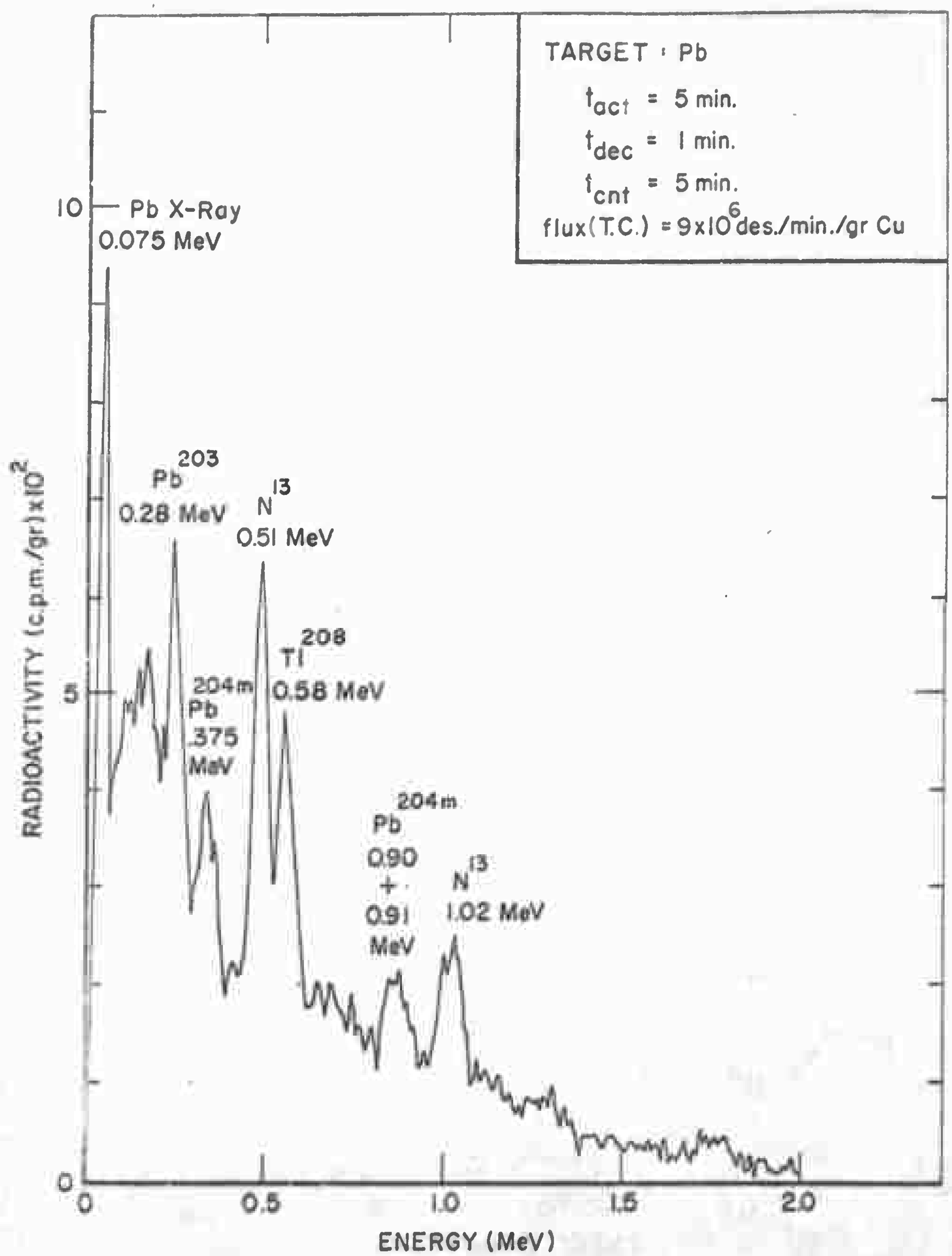


FIGURE III-Pb

TABLE II-Pb

PEAKS OBSERVED IN FIGURES I, II, and III-Pb

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Pb	0.57	$Pb^{207}(n,n')Pb^{207m}$	0.8 s	
		$Pb^{208}(n,2n)Pb^{207m}$	0.8 s	
	0.83	$Pb^{204}(n,2n)Pb^{203m}$	6.1 s	
	1.06	$Pb^{207}(n,n')Pb^{207m}$	0.8 s	
		$Pb^{208}(n,2n)Pb^{207m}$	0.8 s	
	1.63	$Pb^{207}(n,n')Pb^{207m}$	0.8 s	1.06 + 0.57 sum peak
		$Pb^{208}(n,2n)Pb^{207m}$	0.8 s	
II-Pb	0.075			Pb x-ray
	0.59	$Pb^{207}(n,n')Pb^{207m}$	0.8 s	
		$Pb^{208}(n,2n)Pb^{207m}$	0.8 s	
	0.83	$Pb^{204}(n,2n)Pb^{203m}$	6.1 s	
	1.06	$Pb^{207}(n,n')Pb^{207m}$	0.8 s	
		$Pb^{208}(n,2n)Pb^{207m}$	0.8 s	
III-Pb	0.075			Pb x-ray
	0.28	$Pb^{204}(n,2n)Pb^{203}$	52 h	
	0.375	$Pb^{204}(n,n')Pb^{204m}$	64 m	
	0.58	$Pb^{208}(n,p)Tl^{208}$	3.1 m	
	0.90 + 0.91	$Pb^{204}(n,n')Pb^{204m}$	52 h	

TABLE III-Pb

SENSITIVITIES FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg) 1X	5X
0.075	18.3s	6.1s	18.3s	0.4	49	25
0.83	18.3s	6.1s	18.3s	1.0	22	12
0.57	2.4s	0.8s	2.4s	5	7.8	3.5
1.06	2.4s	0.8s	2.4s	3	7.5	5.0
0.075	5 m	1 m	5 m	0.8	132	
0.28	5 m	1 m	5 m	0.5	217	

REMARK: Because of the very short half life of Pb^{207m} (0.8 sec) and Pb^{203m} (6.1sec) five irradiations have been performed, and their spectra accumulated. The 7th column refers to the sensitivities obtained after five irradiations.

TABLE IV-Pb

POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for lead from any other element.

LUTETIUM

TABLE I - Lu

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Lu^{175}	97.41%	$Lu^{175}(n,p)Yb^{175m}$	0.067s	IT 0.50
		$\downarrow Yb^{175}$	4.2d	0.40, 0.11, 0.28, 0.14, 0.25
		$Lu^{175}(n,\alpha)Tm^{172}$	64 h	0.79, 0.18, 1.09
		$Lu^{175}(n,2n)Lu^{174m}$	75 μs	IT 0.133
		$Lu^{175}(n,2n)Lu^{174m}$	165 d-	0.044, 0.99, IT 0.059
		$Lu^{175}(n,2n)Lu^{174}$	300 d	0.077, 1.2
Lu^{176}	2.59%	$Lu^{176}(n,p)Yb^{176m}$	12 s	0.29, 0.39, IT 0.19
		$Lu^{176}(n,\alpha)Tm^{173}$	8.2 h	0.40, 0.47
		$Lu^{176}(n,n')Lu^{176m}$	3.7 h	0.088(?)

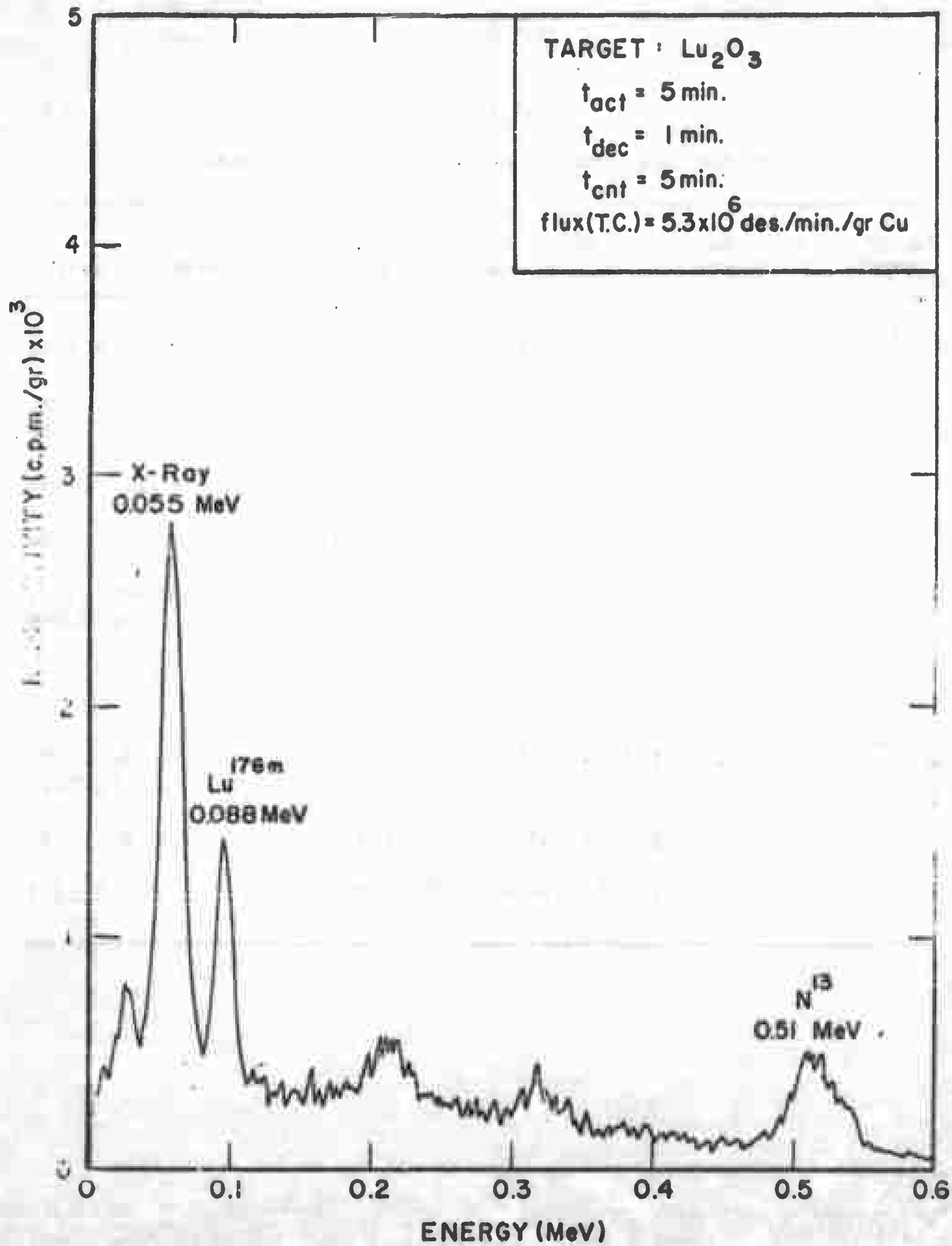

TARGET : Lu_2O_3
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) = 5.3×10^6 des./min./gr Cu
X-Ray
0.055 MeV
Lu^{176m}
0.088 MeV
N^{13}
0.51 MeV
ENERGY (MeV)

FIGURE I-Lu

TABLE II-Lu

PEAKS OBSERVED IN FIGURE I-Lu

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Lu	0.055			x-ray
	0.088	$Lu^{176}(n,n')Lu^{176m}$	3.7 h	0.088

NOTE: Yb^{176m} ($T_{1/2}$+12 sec) not detected for 36 sec irradiation, 12 sec decay and 36 sec counting time.

TABLE III-Lu

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/ mg/T_{cnt}	DETECTION LIMIT, mg
0.055	5 m	1 m	5 m	13	7.5
0.088	5 m	1 m	5 m	5	14.5

TABLE IV-Lu

POSSIBLE INTERFERING REACTIONS

No detectable interferences could be derived for lutetium from any other element.

MAGNESIUM

TABLE I-Mg

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Mg^{24}	78.7 %	$Mg^{24}(n,p)Na^{24m}$	0.02 s	IT 0.47
		$Mg^{24}(n,p)Na^{24}$	15 h	2.75, 1.37
		$Mg^{24}(n,2n)Mg^{23}$	12 s	0.44, $\beta+$
Mg^{25}	10.13%	$Mg^{25}(n,p)Na^{25}$	60 s	0.98, 0.58, 0.40, 1.61
Mg^{26}	11.17%	$Mg^{26}(n,p)Na^{26}$	1 s	1.83
		$Mg^{26}(n,\alpha)Ne^{23}$	38 s	0.44, 1.65

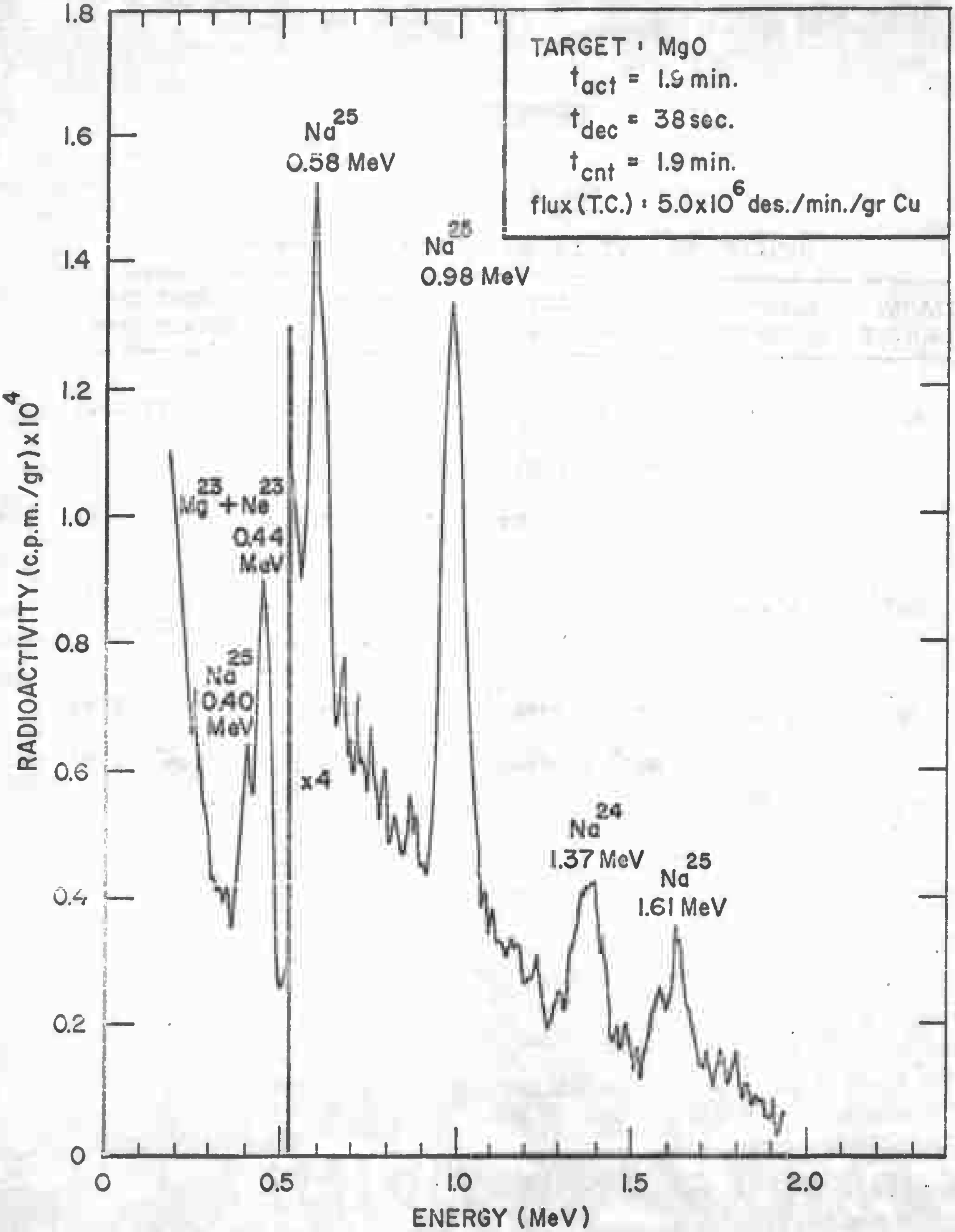

TARGET : MgO
t_{act} = 1.9 min.
t_{dec} = 38 sec.
t_{cnt} = 1.9 min.
flux (T.C.) : 5.0x10^6 des./min./gr Cu
Na^{25} 0.58 MeV
Na^{25} 0.98 MeV
Mg^{23} + Ne^{23} 0.44 MeV
Na^{25} 0.40 MeV
x4
Na^{24} 1.37 MeV
Na^{25} 1.61 MeV
RADIOACTIVITY (c.p.m./gr) x 10^4
ENERGY (MeV)
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
0.5
1.0
1.5
2.0

FIGURE I-Mg

TABLE II-Mg

PEAKS OBSERVED IN FIGURE I-Mg

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Mg	0.40	$Mg^{25}(n,p)Na^{25}$	60 s	
	0.44	$Mg^{24}(n,2n)Mg^{23}$	12 s	
		$Mg^{26}(n,\alpha)Ne^{23}$	38 s	
	0.58	$Mg^{25}(n,p)Na^{25}$	60 s	
	0.98	$Mg^{25}(n,p)Na^{25}$	60 s	
	1.37	$Mg^{24}(n,p)Na^{24}$	15 h	
	1.61	$Mg^{25}(n,p)Na^{25}$	60 s	

NOTE: The photopeak at 2.75 Mev due to Na^{24} is not shown.

Na^{26} ($T_{1/2}$ = 1 sec) not detected for 3 sec irradiation, 1 sec decay and 3 sec counting time.

TABLE III-Mg

SENSITIVITY FOR MAJO.. PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.40 + 0.44	1.9 m	38 s	1.9 m	39	4.5
0.44	36 s	12 s	36 s	15	3.4
0.98	3 m	1 m	3 m	16	8.3
0.58	3 m	1 m	3 m	10	15
1.37	3 m	1 m	3 m	12	10
1.37	5 m	1 m	5 m	33	3.6

TABLE III-Mg (Cont'd.)

NOTE: The peak area for the photopeaks at 0.40 and 0.44 Mev have been combined because of the fact that the NaI(Tl) gamma ray detector cannot resolve these peaks very well. The relative height of the 0.40 and 0.44 Mev peaks will largely depend on the working conditions. To do a quantitative analysis, these conditions have to be rigorously the same because there are three different half lives involved in this dual peak.

The photopeak at 0.98 Mev seems to be the most reliable peak to work with because of the low noise in the spectrum in this region.

TABLE IV-Mg

POSSIBLE INTERFERING REACTIONS

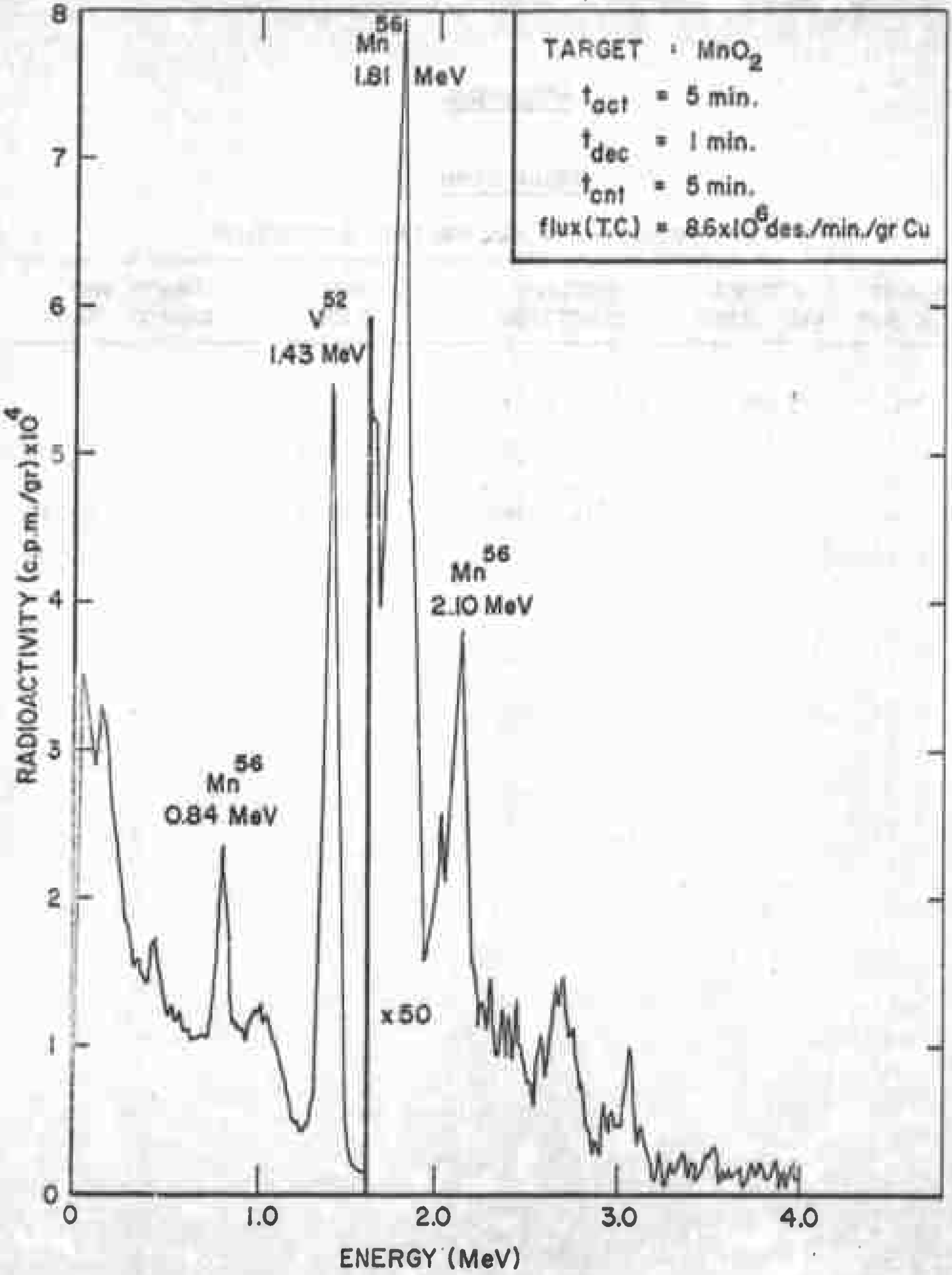
GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.44	Sodium	$Na^{23}(n,p)Ne^{23}$	
1.37	Aluminum	$Al^{27}(n,\alpha)Na^{24}$	

MANGANESE

TABLE I-Mn

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Mn^{55}	100%	$Mn^{55}(n,p)Cr^{55}$	3.5 m	
		$Mn^{55}(n,\alpha)V^{52}$	3.77 m	1.43
		$Mn^{55}(n,2n)Mn^{54}$	303 d	0.84



TARGET : MnO_2
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) = 8.6×10^6 des./min./gr Cu
Mn^{56} 1.81 MeV
V^{52} 1.43 MeV
Mn^{56} 2.10 MeV
Mn^{56} 0.84 MeV
x 50
RADIOACTIVITY (c.p.m./gr) $\times10^4$
ENERGY (MeV)

FIGURE I-Mn

TABLE II-Mn

PEAKS OBSERVED IN FIGURE I-Mn

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Mn	0.84	$Mn^{55}(n,\gamma)Mn^{56}$	2.56 h	(1)
	1.43	$Mn^{55}(n,\alpha)V^{52}$	3.77 m	
	1.81	$Mn^{55}(n,\gamma)Mn^{56}$	2.56 h	(1)
	2.11	$Mn^{55}(n,\gamma)Mn^{56}$	2.56 h	(1)

(1) The activity due to Mn^{56} will be largely dependent on the flux of thermal neutrons present at the irradiation site.

TABLE III-Mn

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
1.43	5 m	1 m	5 m	208	0.49
0.84	5 m	1 m	5 m	35	3.8

TABLE IV-Mn

POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.84	Iron	$Fe^{56}(n,p)Mn^{56}$	
0.84	Cobalt	$Co^{59}(n,\alpha)Mn^{56}$	
1.43	Chromium	$Cr^{52}(n,p)V^{52}$	
1.43	Vanadium	$V^{51}(n,\gamma)V^{52}$	

MERCURY

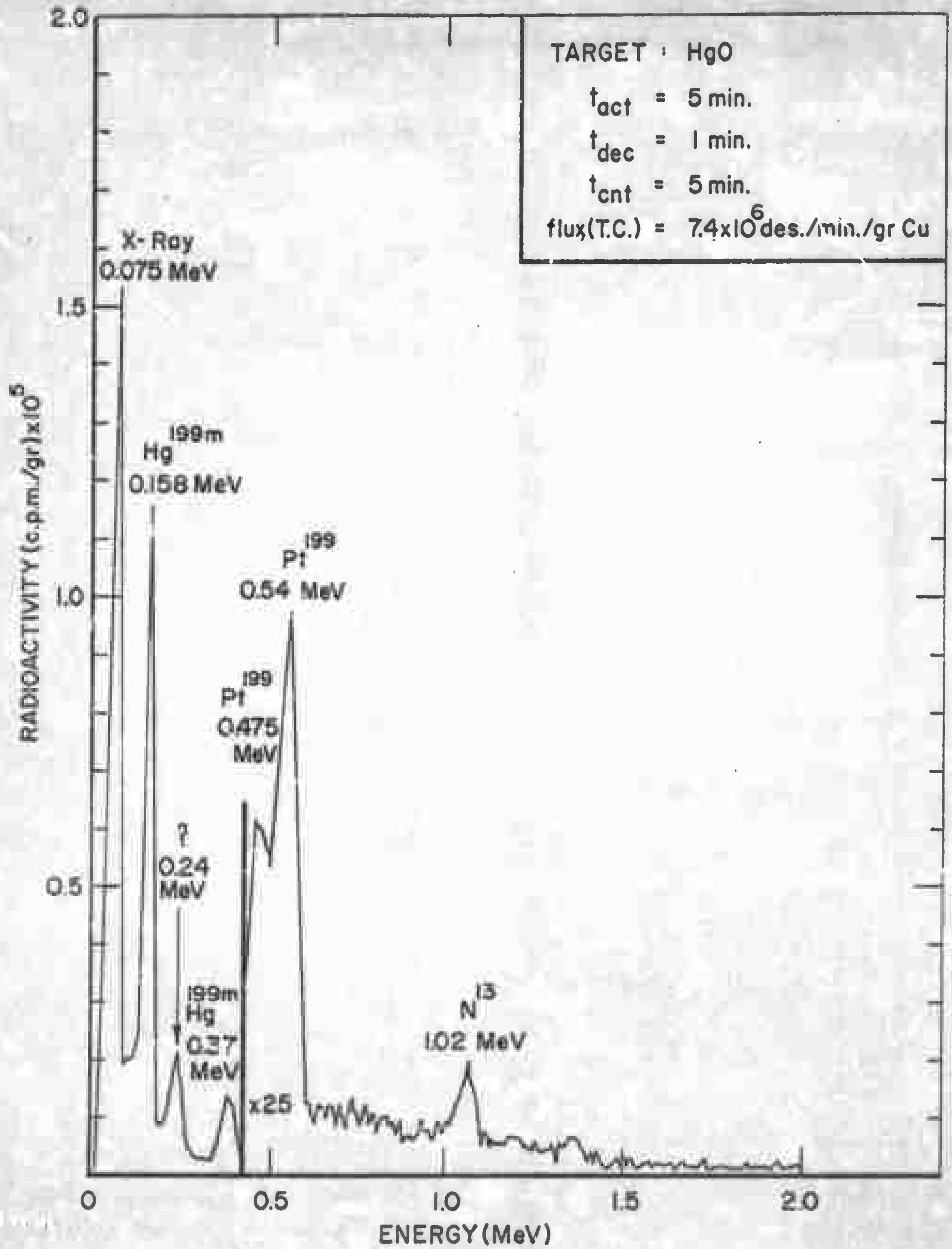
TABLE I-Hg

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Hg^{196}	0.146%	$Hg^{196}(n,p)Au^{196m}$	10 h	0.15, 0.19 IT 0.175
		$Hg^{196}(n,p)Au^{196}$	6.2 d	0.356, 0.333, 0.43
		$Hg^{196}(n,\alpha)Pt^{193m}$	4.4 d	0.013, IT 0.136
		$Hg^{196}(n,\alpha)Pt^{193}$	<500 y	
		$Hg^{196}(n,2n)Hg^{195m}$	40 h	0.016, 0.037, IT 0.123
		$Hg^{196}(n,2n)Hg^{195}$	9.5 h	0.061, 0.18, 0.78, 0.20, 1.17
Hg^{198}	10.02 %	$Hg^{198}(n,p)Au^{198}$	64.8 h	0.412, 0.674
		$Hg^{198}(n,\alpha)Pt^{195m}$	4.1 d	0.099, IT 0.030
		$Hg^{198}(n,2n)Hg^{197m}$	24 h	0.130, 0.41, 0.28, IT 0.165
		$Hg^{198}(n,2n)Hg^{197}$	65 h	0.077, 0.191
Hg^{199}	16.84 %	$Hg^{199}(n,p)Au^{199}$	3.15 d	0.158, 0.208, 0.050
		$Hg^{199}(n,n')Hg^{199m}$	44 m	0.158, IT 0.370

TABLE I-Hg (cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Hg^{200}	23.13%	$Hg^{200}(n,p)Au^{200}$	48 m	1.23, 0.37
		$Hg^{200}(n,\alpha)Pt^{197m}$	2.8 h	
		$Hg^{200}(n,\alpha)Pt^{197m}$	1.5 h	0.05, IT 0.346
		$Hg^{200}(n,\alpha)Pt^{197}$	20 h	0.077, 0.19, 0.27
		$Hg^{200}(n,2n)Hg^{199m}$	44 m	0.158, IT 0.37
Hg^{201}	13.22%	$Hg^{201}(n,p)Au^{201}$	22 m	0.53
		$Hg^{201}(n,n')Hg^{201m}$	100μs	IT 0.53
Hg^{202}		$Hg^{202}(n,p)Au^{202}$	~25 s	
		$Hg^{202}(n,\alpha)Pt^{199m}$	14 s	0.032, IT 0.39
		$Hg^{202}(n,\alpha)Pt^{199}$	30 m	0.54, 0.075, 0.96
		$Hg^{202}(n,2n)Hg^{201m}$	100μs	IT 0.53
Hg^{204}	6.85%	$Hg^{204}(n,\alpha)Pt^{201}$	2.5 m	1.76, 0.23
		$Hg^{204}(n,2n)Hg^{203}$	47 d	0.279



TARGET : HgO
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) = 7.4×10^6 des./min./gr Cu
X- Ray
0.075 MeV
Hg^{199m}
0.158 MeV
Pt^{199}
0.54 MeV
Pt^{199}
0.475
MeV
?
0.24
MeV
199m
Hg
0.37
MeV
x25
N^{13}
1.02 MeV
RADIOACTIVITY (c.p.m./gr) x 10^5
ENERGY (MeV)

FIGURE I-Hg

TABLE II-Hg

PEAKS OBSERVED IN FIGURE I-Hg

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Hg	0.075			x-ray
	0.158	$Hg^{199}(n,n')Hg^{199m}$	44 m	
		$Hg^{200}(n,2n)Hg^{199m}$	44 m	
	0.24		~40 m	
	0.37	$Hg^{199}(n,n')Hg^{199m}$	44 m	
		$Hg^{200}(n,2n)Hg^{199m}$	44 m	
	0.475	$Hg^{202}(n,\alpha)Pt^{199}$	30 m	
	0.54	$Hg^{202}(n,\alpha)Pt^{199}$	30 m	

NOTE: Pt^{199m} ($T_{1/2}$ = 14 sec) not detected for 43 sec irradiation, 14 sec decay and 43 sec counting time.

TABLE III-Hg

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.075	5 m	1 m	5 m	224	0.43
0.158	5 m	1 m	5 m	210	0.46
0.24	5 m	1 m	5 m	38	2.5
0.37	5 m	1 m	5 m	30	3.8

TABLE IV-Hg

POSSIBLE INTERFERING REACTIONS

No detectable interferences could be derived for mercury from any other element.

MOLYBDENUM

TABLE I-Mo

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Mo^{92}	15.84%	$Mo^{92}(n,p)Nb^{92}$	10.1 d	0.93, 0.89, 1.82
		$Mo^{92}(n,\alpha)Zr^{89m}$	4.2 m	1.5, IT 0.59 β+
		$Mo^{92}(n,\alpha)Zr^{89}$	78.4 h	0.91, 1.7, β+
		$Mo^{92}(n,2n)Mo^{91m}$	65 s	1.54, 1.21, IT 0.65, β+
		$Mo^{92}(n,2n)Mo^{91}$	15.5 m	β+
Mo^{94}	9.04%	$Mo^{94}(n,p)Nb^{94m}$	6.3 m	0.87, IT 0.042
		$Mo^{94}(n,p)Nb^{94}$	2×10^4 y	0.87, 0.70
		$Mo^{94}(n,2n)Mo^{93m}$	6.9 h	0.69, 1.48, IT 0.26
		$Mo^{94}(n,2n)Mo^{93}$	10^4 y	
Mo^{95}	15.72%	$Mo^{95}(n,p)Nb^{95m}$	90 h	IT 0.23
		$Mo^{95}(n,p)Nb^{95}$	35 d	0.77
Mo^{96}	16.53%	$Mo^{96}(n,p)Nb^{96}$	23 h	0.77, 0.56, 1.08, 0.22, 1.19
		$Mo^{96}(n,\alpha)Zr^{93}$	9.5×10^5 y	0.029

TABLE I-Mo (cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Mo^{97}	9.46%	$Mo^{97}(n,p)Nb^{97m}$	1 m	IT 0.75
		$\downarrow$ $Mo^{97}(n,p)Nb^{97}$	72 m	0.66
Mo^{98}	23.78%	$Mo^{98}(n,p)Nb^{98}$	51.5 m	0.78, 0.72, 0.33, 2.7
		$Mo^{98}(n,\alpha)Zr^{95}$	65 d	0.72, 0.76, 0.23, 0.77
Mo^{100}	9.63%	$Mo^{100}(n,p)Nb^{100m}$	11.5 m	0.53
		$\downarrow$ $Mo^{100}(n,p)Nb^{100}$	3 m	0.53, 0.36, 0.45, 0.14, 2.9
		$Mo^{100}(n,\alpha)Zr^{97}$	17 h	0.5, 2.6, 0.75
		$Mo^{100}(n,2n)Mo^{99}$	66 h	0.14, 0.74, 0.041, 0.78

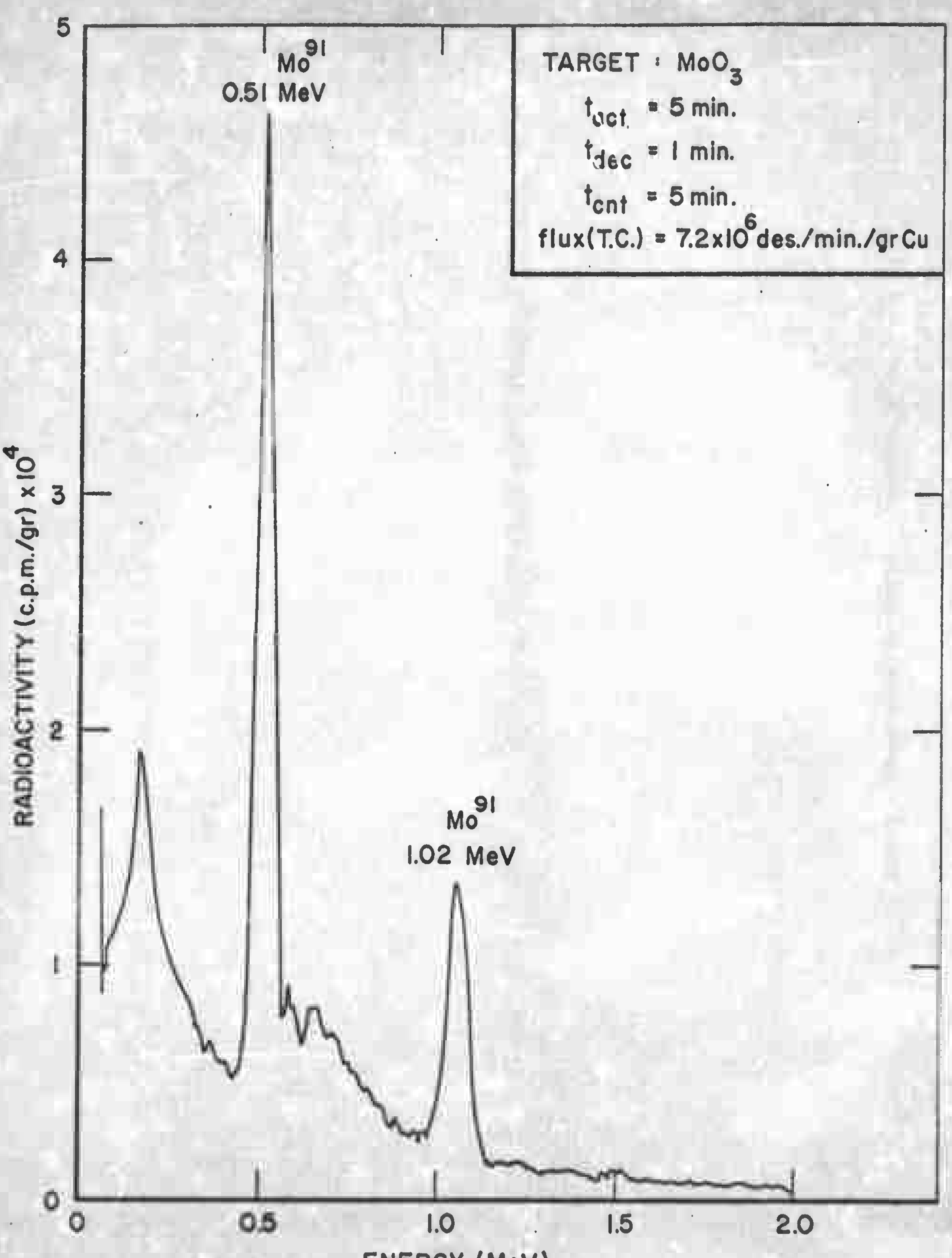

TARGET : MoO3
tact = 5 min.
tdec = 1 min.
tcnt = 5 min.
flux(T.C.) = 7.2x10^6 des./min./gr Cu
Mo91
0.51 MeV
Mo91
1.02 MeV
RADIOACTIVITY (c.p.m./gr) x10^4
ENERGY (MeV)
0
1
2
3
4
5
0
0.5
1.0
1.5
2.0

FIGURE I-Mo

TABLE II-Mo

PEAKS OBSERVED IN FIGURE Mo-I

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Mo	0.51	$Mo^{92}(n,2n)Mo^{91}$	15.5 m	
	1.02	$Mo^{92}(n,2n)Mo^{91}$	15.5 m	0.51 Mev coincidence sum peak

NOTE: Nb^{97m} ($T_{1/2}$ = 1 m) not detected for 3 min irradiation, 1 min decay and 3 min counting time.

TABLE III-Mo

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.51	5 m	1 m	5 m	161	1.0

TABLE IV-Mo

POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for molybdenum from any other element.

For other positron emitting radioisotopes than Mo^{91}, see Section I, Appendix II.

NEODYMIUM

TABLE I-Nd

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Nd^{142}	27.11%	$Nd^{142}(n,p)Pr^{142}$	19.2 h	1.57
		$Nd^{142}(n,\alpha)Ce^{139m}$	55 s	IT 0.74
		$Nd^{142}(n,\alpha)Ce^{139}$	140 d	0.166
		$Nd^{142}(n,2n)Nd^{141m}$	64 s	IT 0.76
		$Nd^{142}(n,2n)Nd^{141}$	2.5 h	1.15, 1.30, $\beta+$
Nd^{143}	12.17%	$Nd^{143}(n,p)Pr^{143}$	13.7 d	
Nd^{144}	23.85%	$Nd^{144}(n,p)Pr^{144}$	17.3 m	0.69, 2.18, 1.49
		$Nd^{144}(n,\alpha)Ce^{141}$	32.5 d	0.145
Nd^{145}	8.30%	$Nd^{145}(n,p)Pr^{145}$	5.9 h	0.072, 1.15
Nd^{146}	17.22%	$Nd^{146}(n,p)Pr^{146}$	24 m	0.46, 1.49, 0.75
		$Nd^{146}(n,\alpha)Ce^{143}$	33 h	0.058, 0.29, 0.66
Nd^{148}	5.73%	$Nd^{148}(n,p)Pr^{148}$	2 m	0.3
		$Nd^{148}(n,\alpha)Ce^{145}$	3 m	

TABLE I-Nd (cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
		$Nd^{148}(n,2n)Nd^{147}$	11.1 d	0.091, 0.53, 0.12, 0.69
Nd^{150}	5.62%	$Nd^{150}(n,\alpha)Ce^{147}$	1.1 m	
		$Nd^{150}(n,2n)Nd^{149}$	1.8 h	0.21, 0.27, 0.11, 0.65

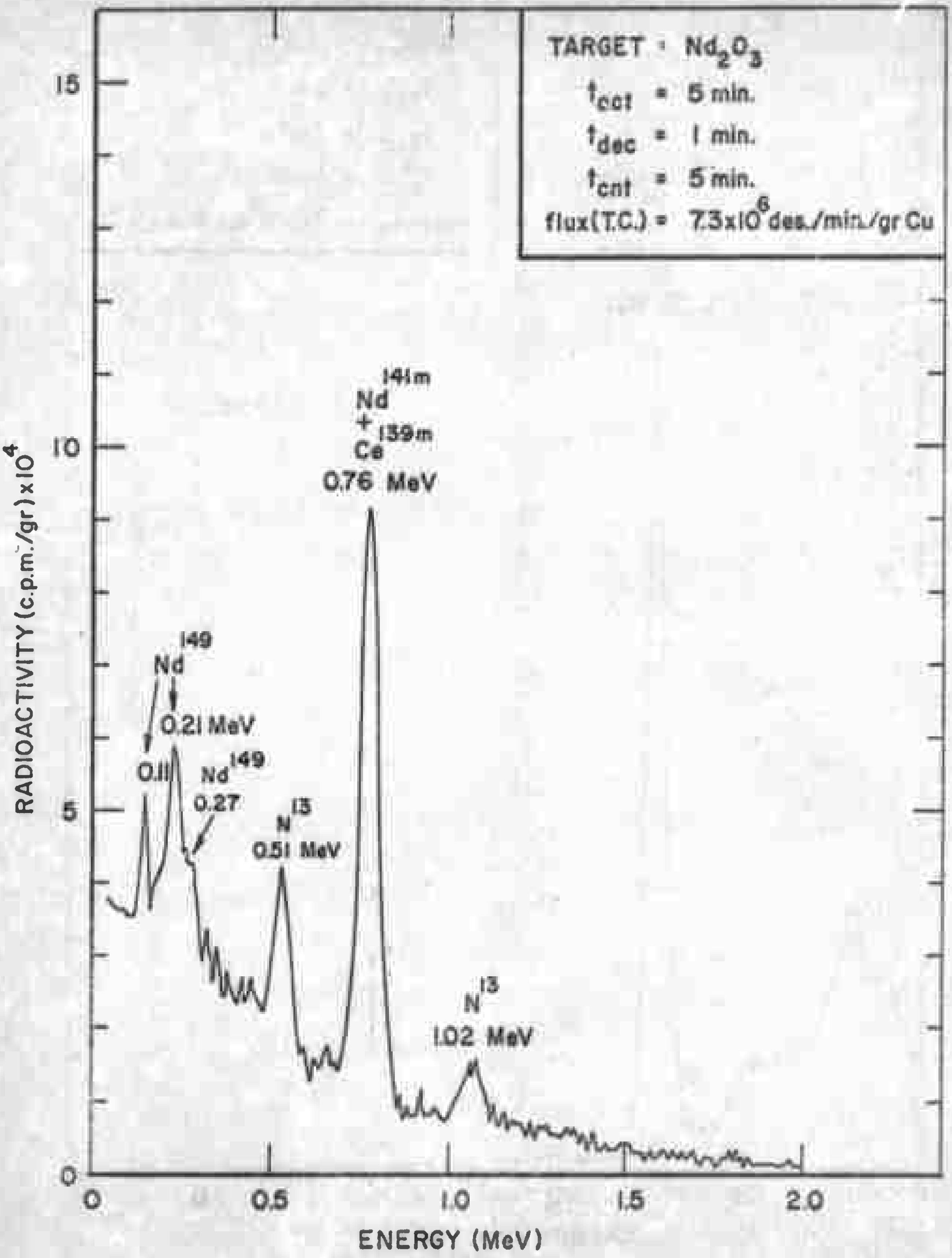

TARGET : Nd_2O_3
t_{cot} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) = 7.3×10^6 des./min./gr Cu
Nd^{141m} + Ce^{139m}
0.76 MeV
Nd^{149}
0.21 MeV
0.11
Nd^{149}
0.27
N^{13}
0.51 MeV
N^{13}
1.02 MeV
RADIOACTIVITY (c.p.m./gr) x 10^4
ENERGY (MeV)
0
5
10
15
0.5
1.0
1.5
2.0

FIGURE I-Nd

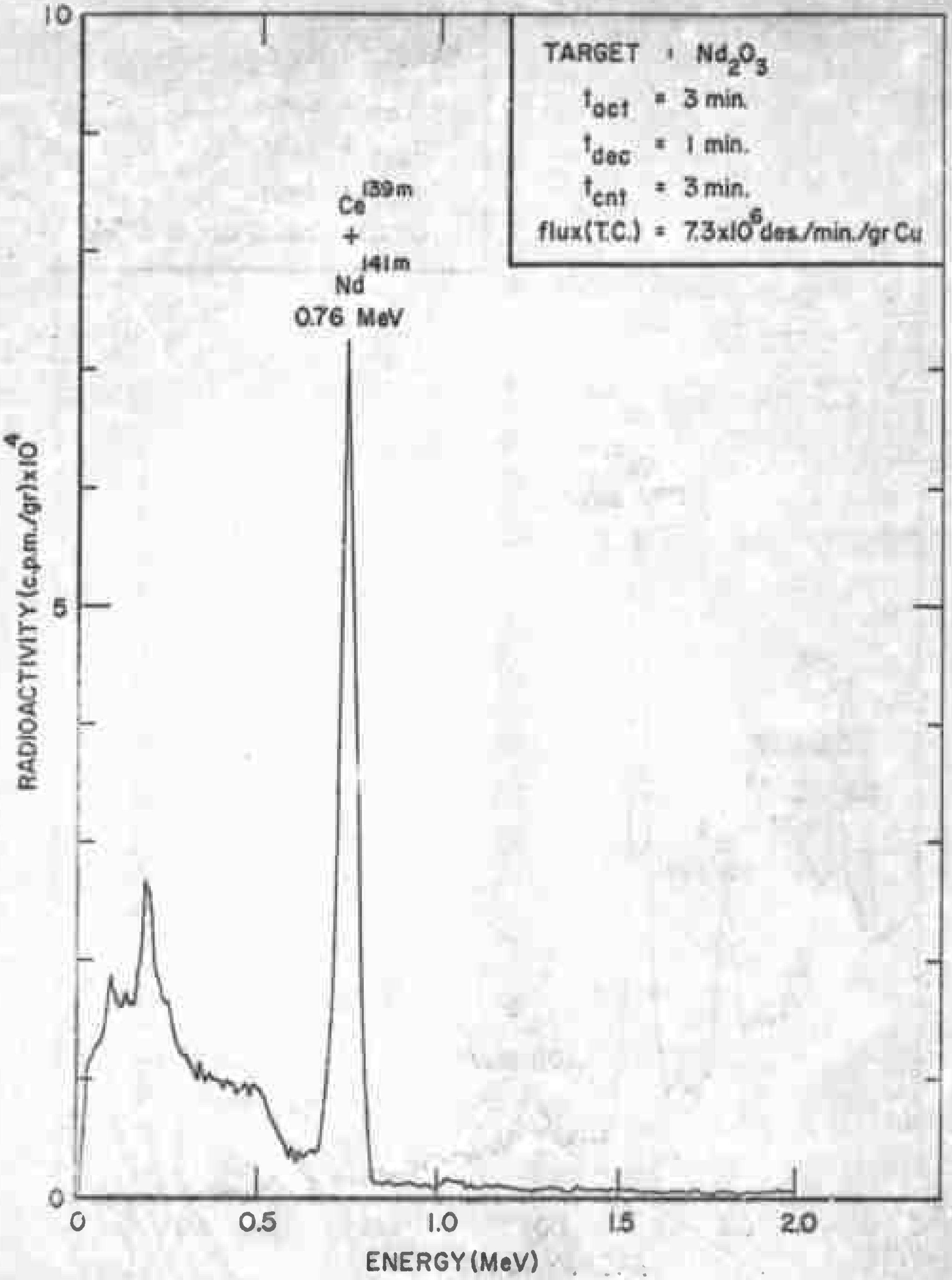

TARGET : Nd_2O_3
t_{act} = 3 min.
t_{dec} = 1 min.
t_{cnt} = 3 min.
flux(T.C.) = 7.3×10^6 des./min./gr Cu
Ce^{139m} + Nd^{141m}
0.76 MeV
RADIOACTIVITY (c.p.m./gr)$\times 10^4$
ENERGY (MeV)
10
5
0
0.5
1.0
1.5
2.0

FIGURE II-Nd

TABLE II-Nd

PEAKS OBSERVED IN FIGURE I-Nd and II-Nd

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Nd	0.11	$Nd^{150}(n,2n)Nd^{149}$	1.8 h	
	0.21	$Nd^{150}(n,2n)Nd^{149}$	1.8 h	
	0.27	$Nd^{150}(n,2n)Nd^{149}$	1.8 h	
	0.76 + 0.74	$Nd^{142}(n,\alpha)Ce^{139m}$	55 s	
		$Nd^{142}(n,2n)Nd^{141m}$	64 s	
II-Nd	0.74 + 0.76	$Nd^{142}(n,2n)Nd^{141m}$	64 s	(1)
		$Nd^{142}(n,\alpha)Ce^{139m}$	55 s	

(1) The sensitivity has been calculated from Figure II-Nd, and Figure I-Nd shows the other photopeaks obtained by longer irradiations.

TABLE III-Nd

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.74 + 0.76	3 m	1 m	3 m	375	0.32

NEODYMIUM

TABLE IV-Nd

POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
~0.76	Cerium	$Ce^{140}(n,2n)Ce^{139m}$	(1)
	Samarium	$Sm^{144}(n,2n)Sm^{143m}$	(1)
	Samarium	$Sm^{144}(n,\alpha)Nd^{141m}$	

(1) Ce^{139m} and Sm^{143m} have a half life respectively of 55 sec and 60 sec, making their identification from Nd^{141m} very difficult.

NICKEL

TABLE I-Ni

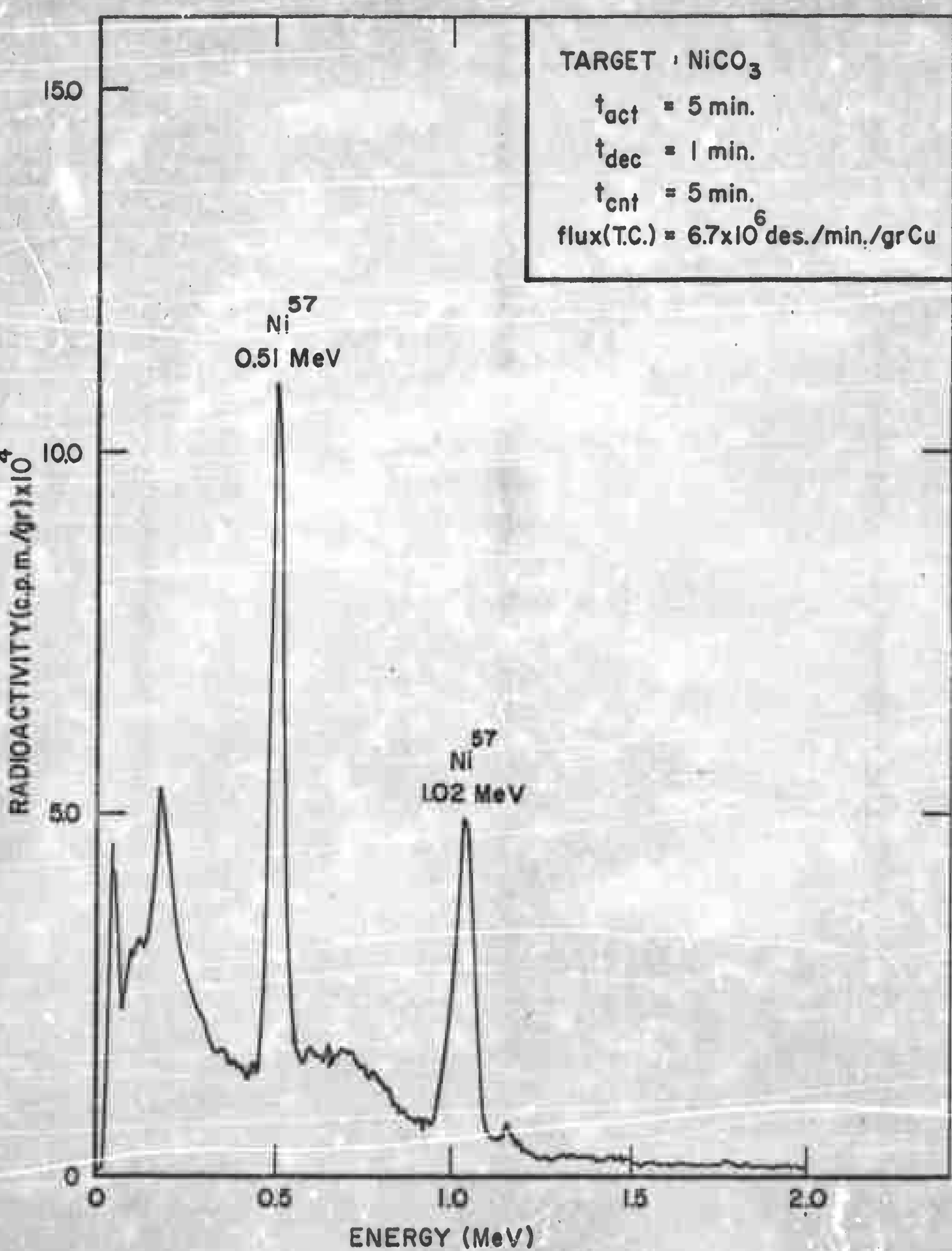
NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Ni^{58}	67.88%	$Ni^{58}(n,p)Co^{58m}$	9 h	IT 0.025
		$Ni^{58}(n,p)Co^{58}$	71 d	0.81, 1.65, $\beta+$
		$Ni^{58}(n,\alpha)Fe^{55}$	2.7 y	
		$Ni^{58}(n,2n)Ni^{57}$	36 h	1.37, 1.89, 0.127, 1.75 $\beta+$
Ni^{60}	26.23%	$Ni^{60}(n,p)Co^{60m}$	10.5 m	1.33, IT 0.059
		$Ni^{60}(n,p)Co^{60}$	5.26 y	1.33, 1.17
		$Ni^{60}(n,2n)Ni^{59}$	8×10^{4} y	
Ni^{61}	1.19%	$Ni^{61}(n,p)Co^{61}$	1.65 h	0.068
Ni^{62}	3.66%	$Ni^{62}(n,p)Co^{62m}$	1.9 m	
		$Ni^{62}(n,p)Co^{62}$	13.9 m	1.17, 1.47, 1.74, 2.03
		$Ni^{62}(n,\alpha)Fe^{59}$	45 d	1.10, 1.29, 0.19

NICKEL

TABLE I-Ni (cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Ni^{64}	1.08%	$Ni^{64}(n,p)Co^{64m}$	2 m	
		$\downarrow$ $Ni^{64}(n,p)Co^{64}$	7.8 m	
		$Ni^{64}(n,\alpha)Fe^{61}$	6.0 m	0.29
		$Ni^{64}(n,2n)Ni^{63}$	92 y	



TARGET : $NiCO_3$
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) = 6.7×10^6 des./min./gr Cu
Ni^{57}
0.51 MeV
Ni^{57}
1.02 MeV
15.0
10.0
5.0
0
RADIOACTIVITY(c.p.m./gr)x10^4
0
0.5
1.0
1.5
2.0
ENERGY (MeV)

FIGURE I-Ni

TABLE II-Ni

PEAKS OBSERVED IN FIGURE I-Ni

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Ni	0.51	$Ni^{58}(n,2n)Ni^{57}$	36 h	
	1.02	$Ni^{58}(n,2n)Ni^{57}$	36 h	0.51 Mev coincidence sum peak

TABLE III-Ni

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.51	5 m	1 m	5 m	320	0.52

TABLE IV-Ni

POSSIBLE INTERFERING REACTIONS

No detectable interferences could be derived for nickel from any other element.

For other positron emitting radioisotopes than Ni^{67}, see Section I, Appendix II.

NIOBIUM

TABLE I-Nb

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Nb^{93}	100%	$Nb^{93}(n,p)Zr^{93}$	9.5×10^5 y	0.029
		$Nb^{93}(n,\alpha)Y^{90m}$ ↓	3.2 h	0.20, 2.3, IT 0.48
		$Nb^{93}(n,\alpha)Y^{90}$	64.2 h	1.75
		$Nb^{93}(n,n')Nb^{93m}$	3.7 y	IT 0.029
		$Nb^{93}(n,2n)Nb^{92}$	10.1 d	0.93, 0.89, 1.82

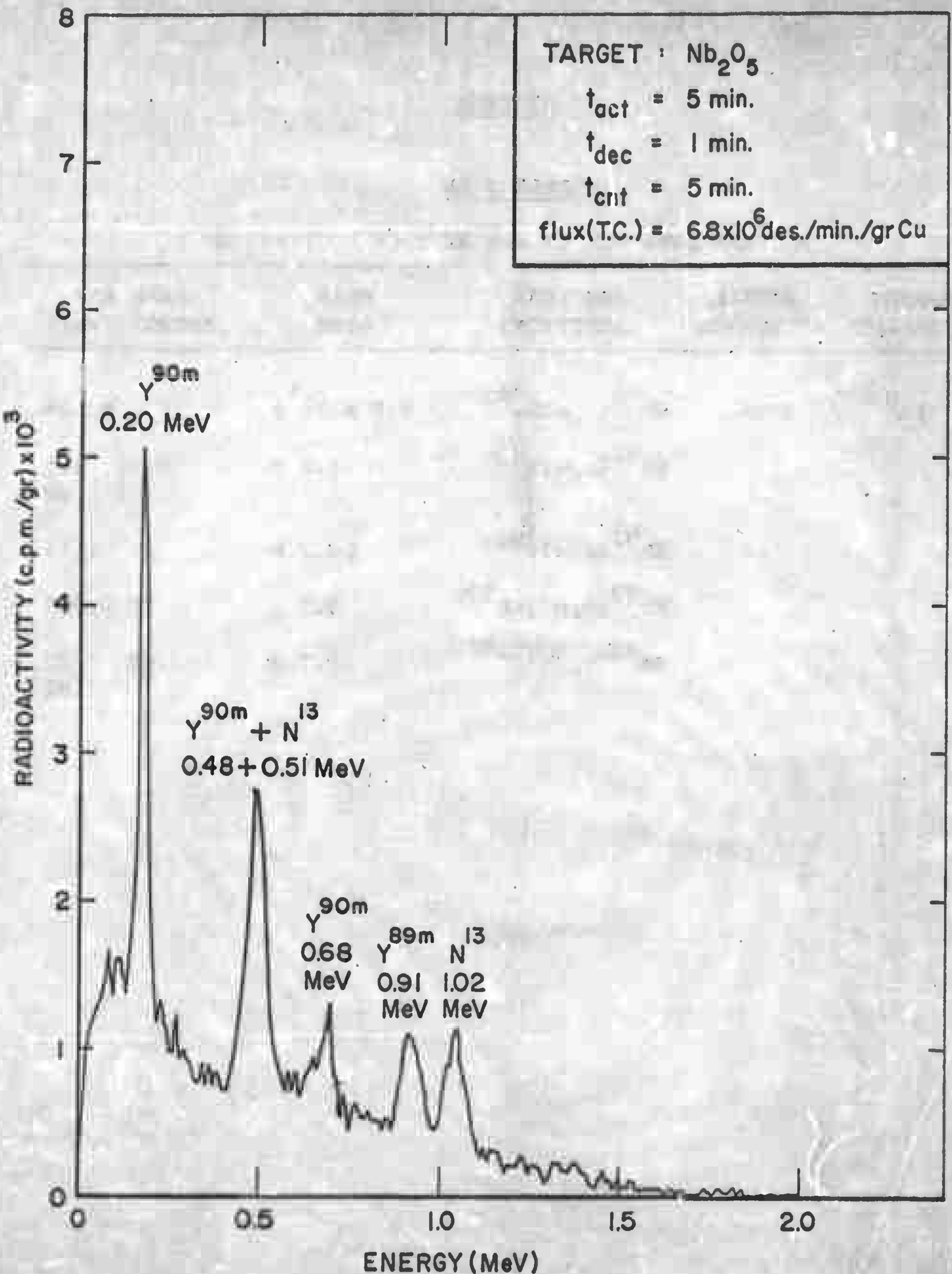

TARGET : Nb_2O_5
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) = 6.8×10^6 des./min./gr Cu
Y^{90m}
0.20 MeV
$Y^{90m} + N^{13}$
0.48 + 0.51 MeV
Y^{90m}
0.68
MeV
Y^{89m}
0.91
MeV
N^{13}
1.02
MeV
RADIOACTIVITY (c.p.m./gr) x 10^3
ENERGY (MeV)
0
1
2
3
4
5
6
7
8
0
0.5
1.0
1.5
2.0

FIGURE I-Nb

TABLE II-Nb

PEAKS OBSERVED IN FIGURE I-Nb

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Nb	0.20	$Nb^{93}(n,\alpha)Y^{90m}$	3.2 h	
	0.48 + 0.51	$Nb^{93}(n,\alpha)Y^{90m}$	3.2 h	
	0.68	$Nb^{93}(n,\alpha)Y^{90m}$	3.2 h	0.48 + 0.20 sum peak
	0.91	$Nb^{93}(n,n'\alpha)Y^{89m}$	16 s	

TABLE III-Nb

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.20	5 m	1 m	5 m	7	18

TABLE IV-Nb

POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.20	Zirconium	$Zr^{90}(n,p)Y^{90m}$	

NITROGEN

TABLE I-N

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
N^{14}	99.63%	$N^{14}(n,p)C^{14}$	5730 y	
		$N^{14}(n,2n)N^{13}$	9.96 m	$\beta+$
N^{15}	0.37%	$N^{15}(n,p)C^{15}$	2.25 s	5.30
		$N^{15}(n,\alpha)B^{12}$	0.020 s	4.4

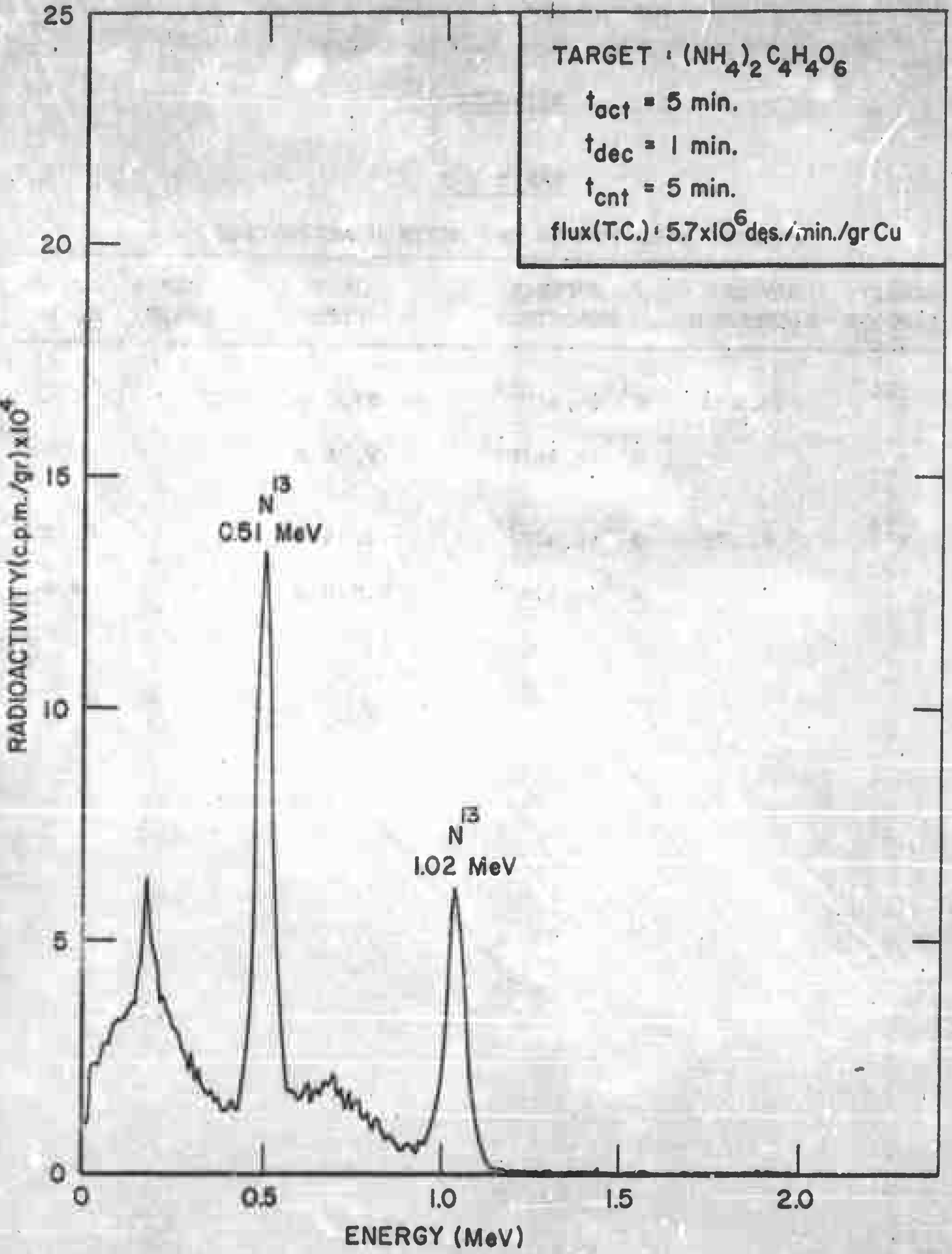

TARGET : $(NH_4)_2C_4H_4O_6$
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) : 5.7×10^6 des./min./gr Cu
N^{13}
0.51 MeV
N^{13}
1.02 MeV
RADIOACTIVITY(c.p.m./gr)x10^4
25
20
15
10
5
0
0
0.5
1.0
1.5
2.0
ENERGY (MeV)

FIGURE I-N

TABLE II-N

PEAKS OBSERVED IN FIGURE I-N

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-N	0.51	$N^{14}(n,2n)N^{13}$	9.96 m	
	1.02	$N^{14}(n,2n)N^{13}$	9.96 m	0.51 Mev coincidence sum peak

TABLE III-N

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT (mg)
0.51	5 m	1 m	5 m	350	0.47

NOTE: When organic compounds, or water solutions are used, the blank activity due to the $C^{13}(p,n)N^{13}$ and $O^{16}(p,\alpha)N^{13}$ have to be taken in account. The activity depends respectively from the (C)/(H) and (O)/(H) ratio.

TABLE IV-N

POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.51	Copper	$Cu^{63}(n,2n)Cu^{62}$	(1)
	Samarium	$Sm^{144}(n,2n)Sm^{143}$	(1)

Cu^{62} and Sm^{143} have a half life respectively of 9.9 m and 9 m, making their identification from N^{13} very difficult.

For other positron emitting radioisotopes than N^{13}, see Section I, Appendix II.

PALLADIUM

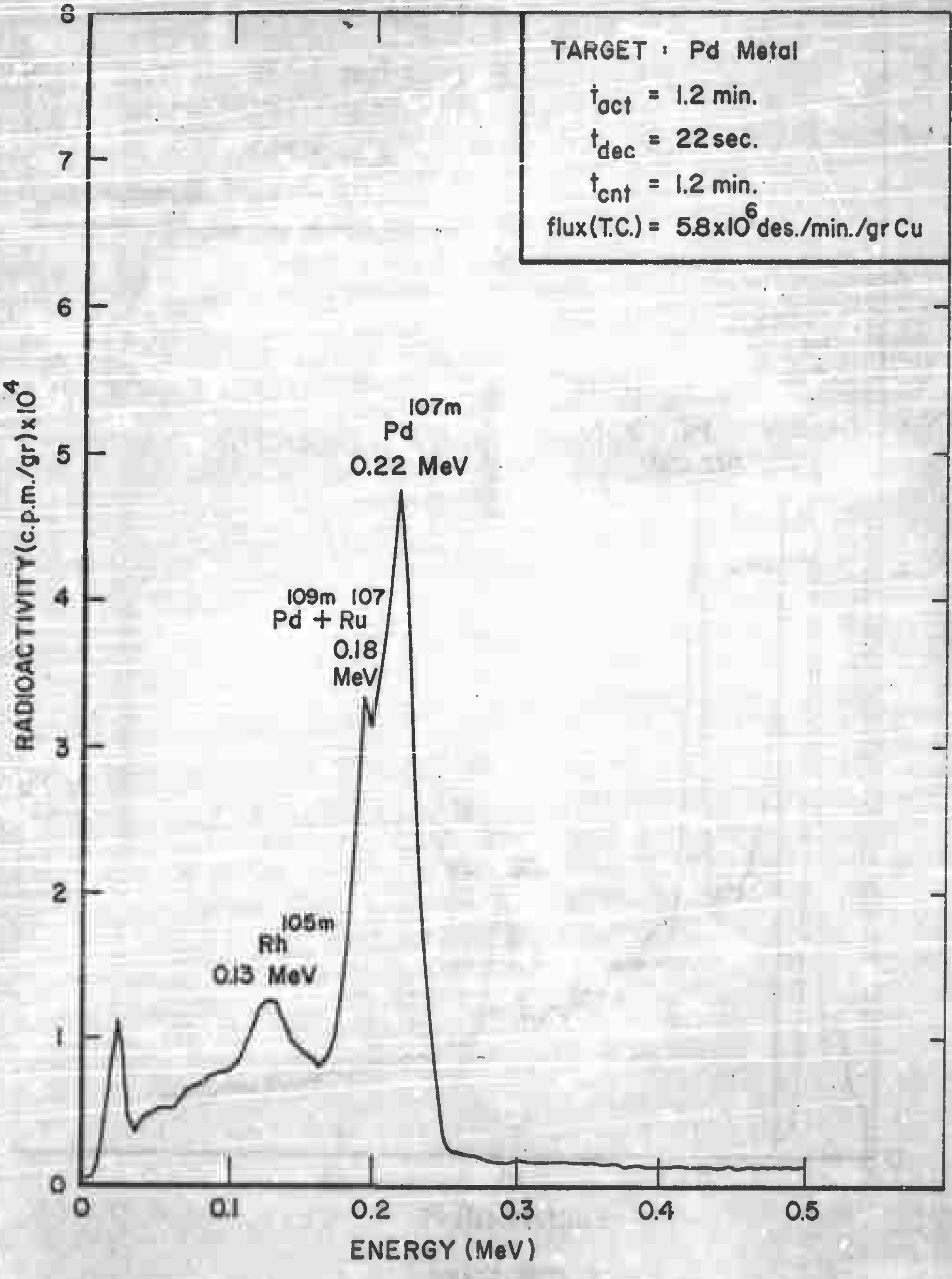
TABLE I-Pd

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Pd^{102}	0.96%	$Pd^{102}(n,p)Rh^{102m}$	2.9 y	β+
		$Pd^{102}(n,p)Rh^{102}$	206 d	0.47, 0.51, 0.42, 2.06, β+
		$Pd^{102}(n,2n)Pd^{101}$	8.5 h	0.024, 0.296, 0.590, 0.269, 1.31, β+
Pd^{104}	10.97	$Pd^{104}(n,p)Rh^{104m}$	4.4 m	0.051, IT 0.077
		$Pd^{104}(n,p)Rh^{104}$	42 s	0.56, 1.24
		$Pd^{104}(n,2n)Pd^{103}$	17 d	0.040, 0.052, 0.36
Pd^{105}	22.23%	$Pd^{105}(n,p)Rh^{105m}$	30 s	IT 0.130
		$Pd^{105}(n,p)Rh^{105}$	36 h	0.31, 0.32
		$Pd^{105}(n,n')Pd^{105m}$	37μs	0.32, IT 0.18
Pd^{106}	27.33%	$Pd^{106}(n,p)Rh^{106m}$	2.2 h	0.51, 0.22, 1.22
		$Pd^{106}(n,p)Rh^{106}$	30 s	0.51, 0.62, 0.7, 3.4

TABLE I-Pd (cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
		$Pd^{106}(n,\alpha)Ru^{103}$	40 d	0.040, 0.50, 0.05, 0.61
		$Pd^{106}(n,2n)Pd^{105m}$	37μs	0.32, IT 0.18
Pd^{108}	26.71%	$Pd^{108}(n,p)Rh^{108}$	17 s	0.43, 0.62, 0.51, 1.52
		$Pd^{108}(n,\alpha)Ru^{105}$	4.43 h	0.72, 0.21, 1.7
		$Pd^{108}(n,2n)Pd^{107m}$	22 s	IT 0.22
		$Pd^{108}(n,2n)Pd^{107}$	7×10^{6} y	
Pd^{110}	11.81%	$Pd^{110}(n,p)Rh^{110}$	5 s	0.38
		$Pd^{110}(n,\alpha)Ru^{107}$	4.2 m	0.19, 0.37, 1.3
		$Pd^{110}(n,2n)Pd^{109m}$	4.8 m	IT 0.18
		$Pd^{110}(n,2n)Pd^{109}$	13.5 h	0.088



TARGET : Pd Metal
t_{act} = 1.2 min.
t_{dec} = 22 sec.
t_{cnt} = 1.2 min.
flux(T.C.) = 5.8×10^6 des./min./gr Cu
^{107m}Pd
0.22 MeV
$^{109m}Pd + ^{107}Ru$
0.18 MeV
^{105m}Rh
0.13 MeV
RADIOACTIVITY (c.p.m./gr) $\times 10^4$
ENERGY (MeV)
0
1
2
3
4
5
6
7
8
0.1
0.2
0.3
0.4
0.5

FIGURE I-Pd

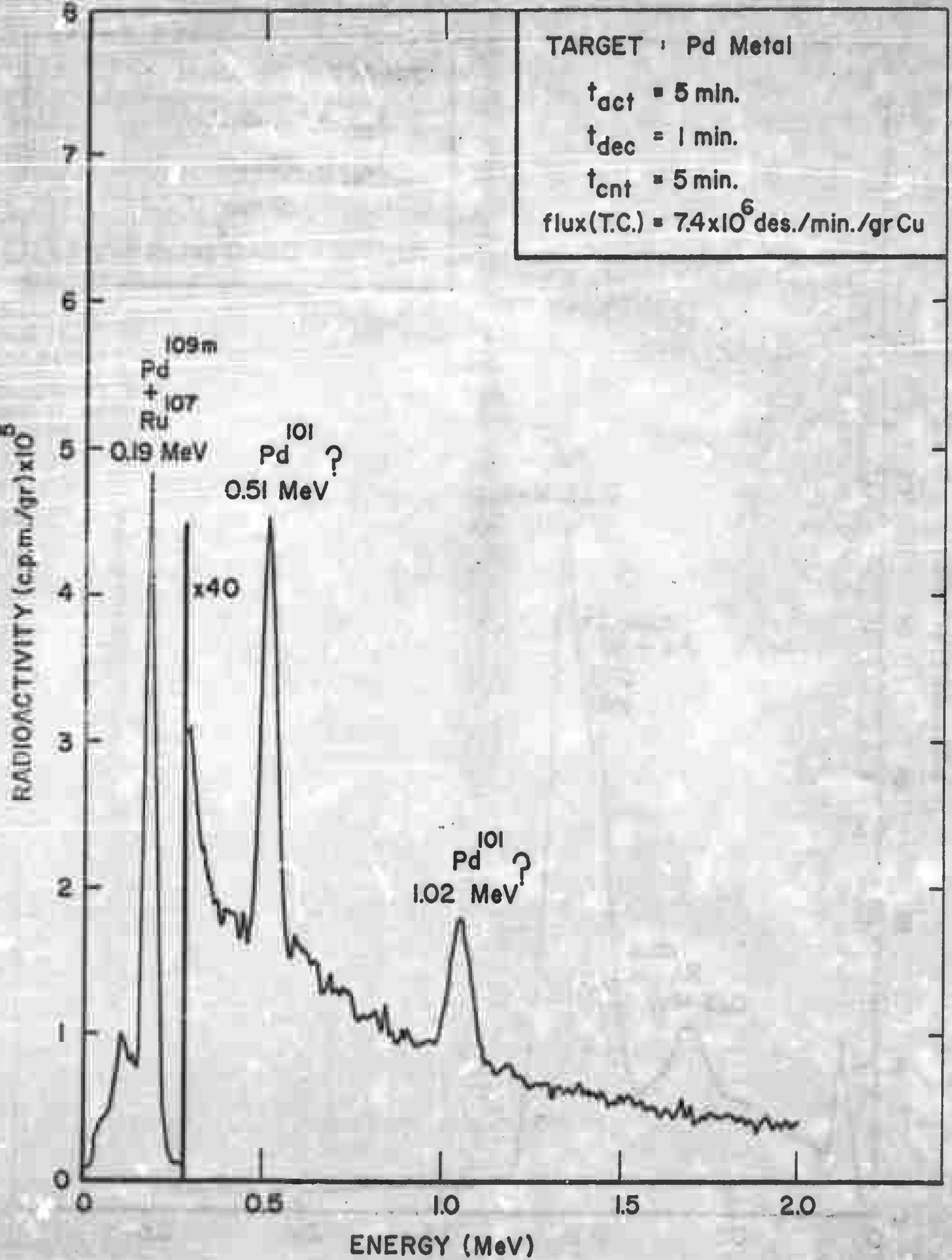

TARGET : Pd Metal
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) = 7.4×10^6 des./min./gr Cu
Pd^{109m} + Ru^{107}
0.19 MeV
x40
Pd^{101} ?
0.51 MeV
Pd^{101} ?
1.02 MeV
RADIOACTIVITY (c.p.m./gr.) $\times 10^5$
0
1
2
3
4
5
6
7
8
0
0.5
1.0
1.5
2.0
ENERGY (MeV)

FIGURE II-Pd

TABLE II-Pd

PEAKS OBSERVED IN FIGURE I-Pd and II-Pd

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Pd	0.13	$Pd^{105}(n,p)Rh^{105m}$	30 s	
	0.18 + 0.19	$Pd^{110}(n,2n)Pd^{109m}$	4.8 m	
		$Pd^{110}(n,\alpha)Ru^{107}$	4.2 m	
	0.22	$Pd^{108}(n,2n)Pd^{107m}$	22 s	
II-Pd	0.13	$Pd^{105}(n,p)Rh^{105m}$	30 s	
	0.18 + 0.19	$Pd^{110}(n,2n)Pd^{109m}$	4.8 m	
		$Pd^{110}(n,\alpha)Ru^{107}$	4.2 m	(1)
	0.51	$Pd^{102}(n,2n)Pd^{101}$	8.5 h	probable
	1.02	$Pd^{102}(n,2n)Pd^{101}$	8.5 h	0.51 Mev coincidence sum peak

(1) The major activity at 0.19 Mev is due to Ru^{107} and Pd^{109m}.

NOTE: Rh^{110} ($T_{1/2}$ = 5 sec) not detected for 15 sec irradiation, 5 sec decay and 15 sec counting time.

TABLE III-Pd

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.18+0.19+0.22	1.2 m	22 s	1.2 m	308	0.54
0.18+0.19	5 m	1 m	5 m	732	0.40

TABLE IV-Pd

POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for palladium from any other element.

PHOSPHORUS

TABLE I-P

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
P^{31}	100%	$P^{31}(n,p)Si^{31}$	2.62 h	1.27
		$P^{31}(n,\alpha)Al^{28}$	2.30 m	1.78
		$P^{31}(n,2n)P^{30}$	2.5 m	2.24, $\beta+$

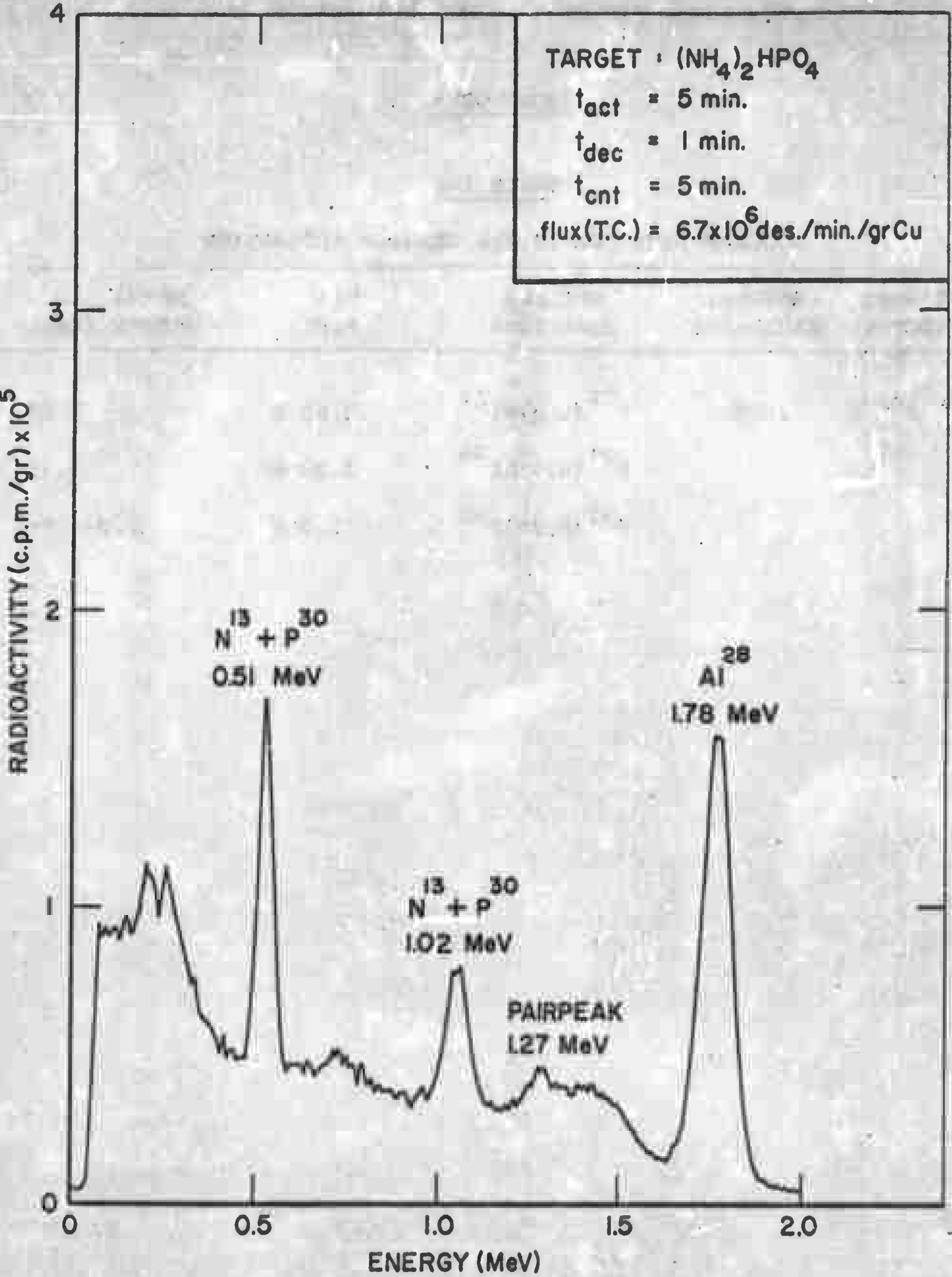

TARGET : $(NH_4)_2HPO_4$
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) = 6.7×10^6 des./min./gr Cu
$N^{13}+P^{30}$
0.51 MeV
$N^{13}+P^{30}$
1.02 MeV
PAIRPEAK
1.27 MeV
Al^{28}
1.78 MeV
RADIOACTIVITY (c.p.m./gr) x 10^5
ENERGY (MeV)
0
1
2
3
4
0
0.5
1.0
1.5
2.0

FIGURE I-P

TABLE II-P

PEAKS OBSERVED IN FIGURE I-P

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-P	0.51	$P^{31}(n,2n)P^{30}$	2.5 m	
	1.02	$P^{31}(n,2n)P^{30}$	2.5 m	0.51 Mev coincidence sum peak
	1.78	$P^{31}(n,\alpha)Al^{28}$	2.30m	

TABLE III-P

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.51	5 m	1 m	5 m	179 (1)	0.92
1.78	5 m	1 m	5 m	1360	0.04

(1) The contribution of nitrogen, present in $(NH_4)_2HPO_4$, to the 0.51 Mev photopeak is equal to 315 counts. This value has been subtracted from the $N^{13} + P^{30}$ activity.

TABLE IV-P

POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
1.78	Silicon	$Si^{28}(n,p)Al^{28}$	
	Aluminum	$Al^{27}(n,\gamma)Al^{28}$	

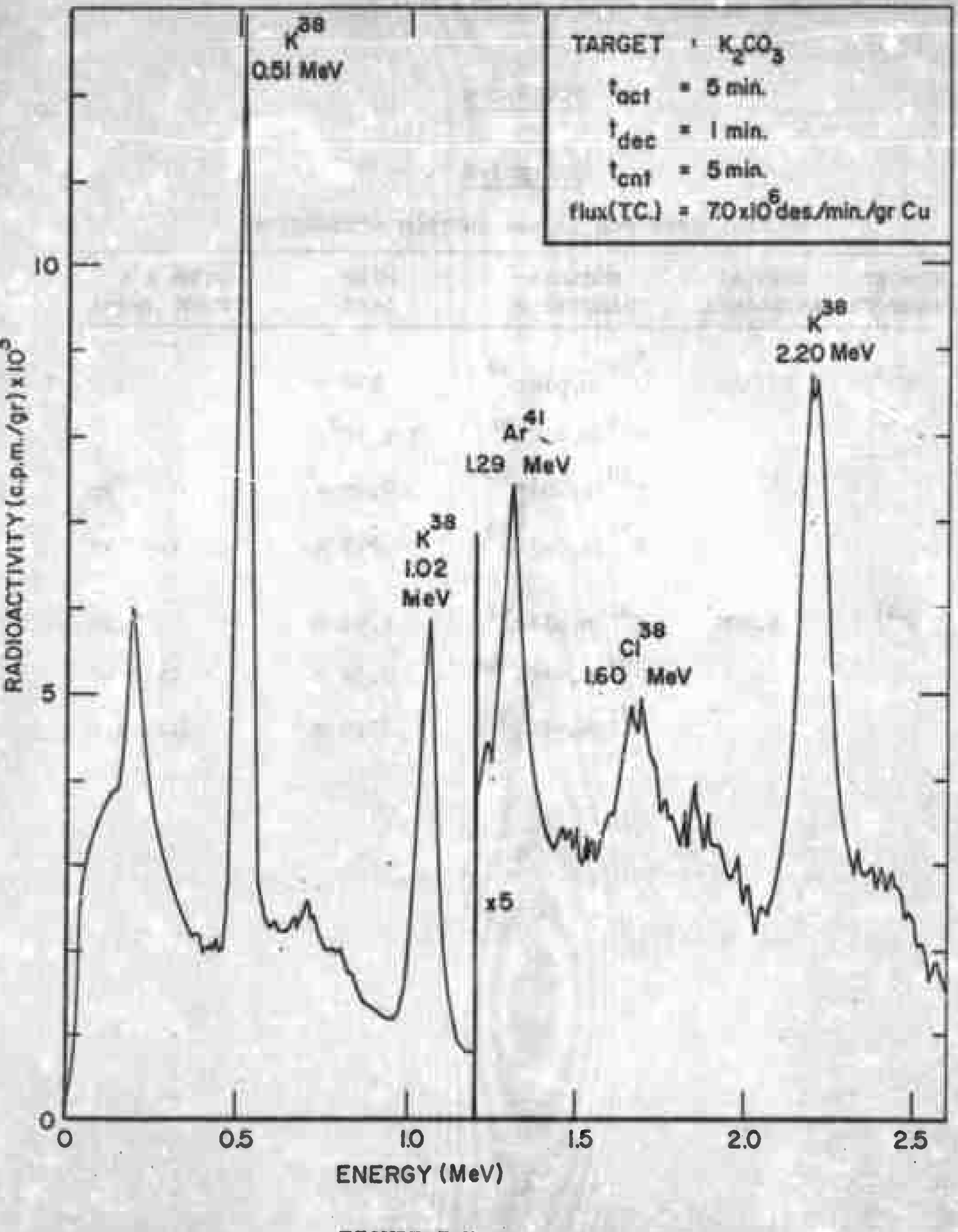
For other positron emitting radioisotopes besides P^{30}, see Section I, Appendix II.

POTASSIUM

TABLE I-K

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
K^{39}	93.10%	$K^{39}(n,p)Ar^{39}$	270 y	
		$K^{39}(n,\alpha)Cl^{36}$	3×10^5 y	
		$K^{39}(n,2n)K^{38m}$	0.95 s	$\beta+$
		$K^{39}(n,2n)K^{38}$	7.7 m	2.2, $\beta+$
K^{41}	6.88%	$K^{41}(n,p)Ar^{41}$	1.83 h	1.29
		$K^{41}(n,\alpha)Cl^{38m}$	0.74 s	IT 0.66
		$K^{41}(n,\alpha)Cl^{38}$	37.3 m	2.2, 1.6



TARGET : K_2CO_3
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) = 7.0×10^6 des./min./gr Cu
K^{38}
0.51 MeV
K^{38}
1.02
MeV
Ar^{41}
1.29 MeV
Cl^{38}
1.60 MeV
K^{38}
2.20 MeV
x5
RADIOACTIVITY (c.p.m./gr) x 10^3
ENERGY (MeV)
0
5
10
0.5
1.0
1.5
2.0
2.5

FIGURE I-K

TABLE II-K

PEAKS OBSERVED IN FIGURE I-K

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-K	0.51	$K^{39}(n,2n)K^{38}$	7.7 m	
	1.02	$K^{39}(n,2n)K^{38}$	7.7 m	0.51 Mev coincidence sum peak
	1.29	$K^{41}(n,p)Ar^{41}$	1.83h	
	1.6	$K^{41}(n,\alpha)Cl^{38}$	37.3 m	
	2.2	$K^{41}(n,\alpha)Cl^{38}$	37.3 m	
		$K^{39}(n,2n)K^{38}$	7.7 m	

TABLE III-K

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.51	5 m	1 m	5 m	48	3.4

TABLE IV-K

POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for potassium from any other element.

For other positron emitting radioisotopes than K^{38}, see Section I. Appendix II.

PRASEODYMIUM

TABLE I-Pr

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Pr^{141}	100%	$Pr^{141}(n,p)Ce^{141}$	32.5 d	0.145
		$Pr^{141}(n,2n)Pr^{140}$	3.4 m	1.6, 1.9, 0.3, β+

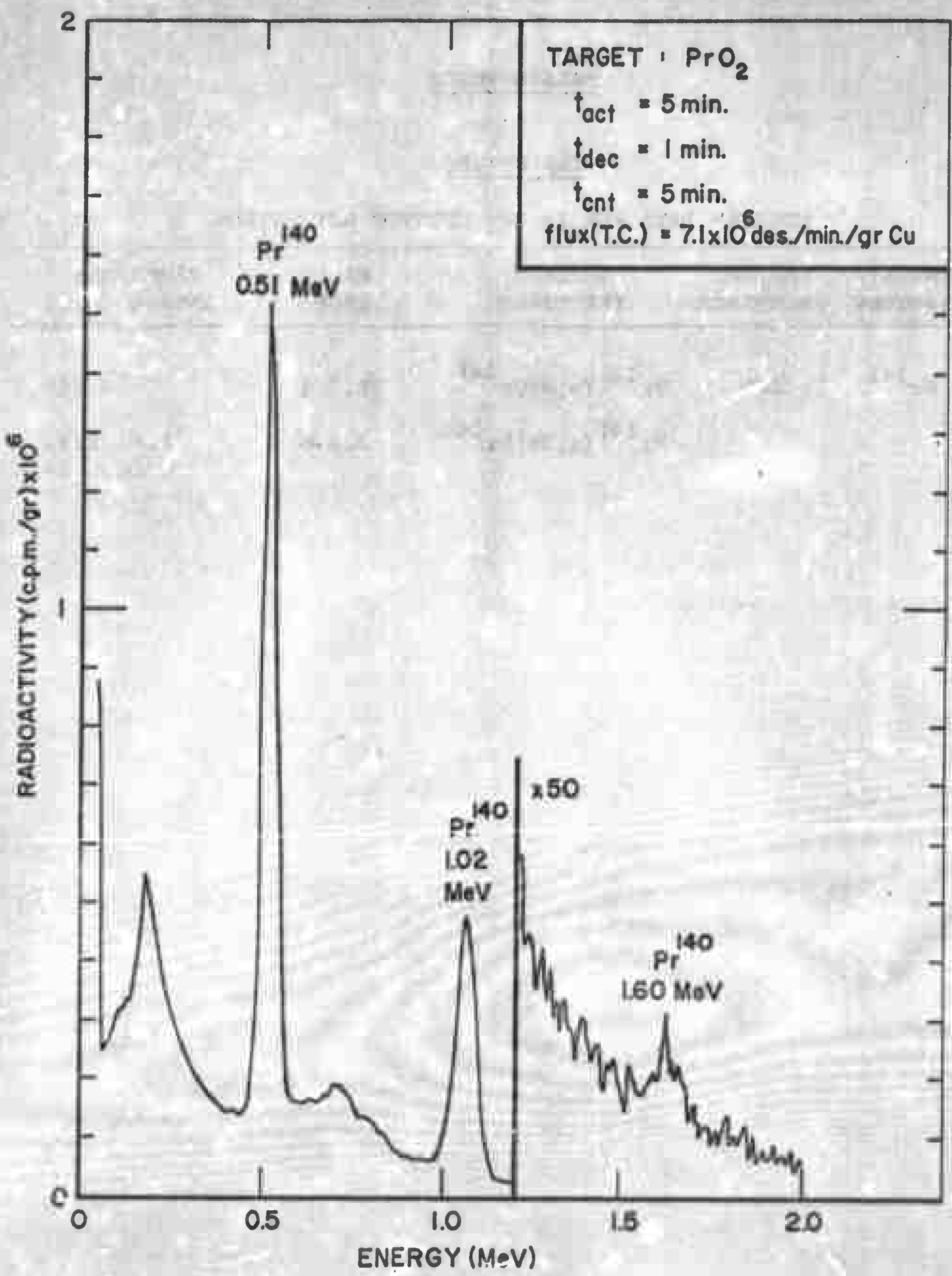

TARGET : PrO_2
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) = 7.1×10^6 des./min./gr Cu
Pr^{140} 0.51 MeV
Pr^{140} 1.02 MeV
x50
Pr^{140} 1.60 MeV
RADIOACTIVITY (c.p.m./gr) x 10^6
ENERGY (MeV)
0
0.5
1.0
1.5
2.0
2
1

FIGURE I-Pr

TABLE II-Pr

PEAKS OBSERVED IN FIGURE I-Pr

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Pr	0.51	$Pr^{141}(n,2n)Pr^{140}$	3.4 m	
	1.02	$Pr^{141}(n,2n)Pr^{140}$	3.4 m	0.51 Mev coincidence sum peak
	1.60	$Pr^{141}(n,2n)Pr^{140}$	3.4 m	

TABLE III-Pr

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.51	5 m	1 m	5 m	5400	0.03

TABLE IV-Pr

POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for praseodymium from any other element.

For other positrons emitting radioisotopes than Pr^{140}, see Section I, Appendix II.

RUBIDIUM

TABLE I-Rb

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Rb^{85}	72.15%	$Rb^{85}(n,p)Kr^{85m}$	4.4 h	0.15, IT 0.31
		$Rb^{85}(n,p)Kr^{85}$	10.76 y	0.52
		$Rb^{85}(n,\alpha)Br^{82m}$	6.1 m	0.78, 1.48, IT 0.046
		$Rb^{85}(n,\alpha)Br^{82}$	35.3 h	0.78, 0.55, 0.62, 0.70, 1.48
		$Rb^{85}(n,2n)Rb^{84m}$	20 m	0.24, 0.48, IT 0.46, 0.22
		$Rb^{85}(n,2n)Rb^{84}$	33 d	0.88, 1.01, 1.90, β+
Rb^{87}	27.85%	$Rb^{87}(n,p)Kr^{87}$	76 m	0.40, 2.57, 0.85
		$Rb^{87}(n,\alpha)Br^{84m}$	6 m	0.88, 1.46,
		$Rb^{87}(n,\alpha)Br^{84}$	32 m	0.88, 2.1, 1.9, 0.27, 3.9
		$Rb^{87}(n,2n)Rb^{86m}$	1 m	IT 0.56
		$Rb^{87}(n,2n)Rb^{86}$	18.7 d	1.08

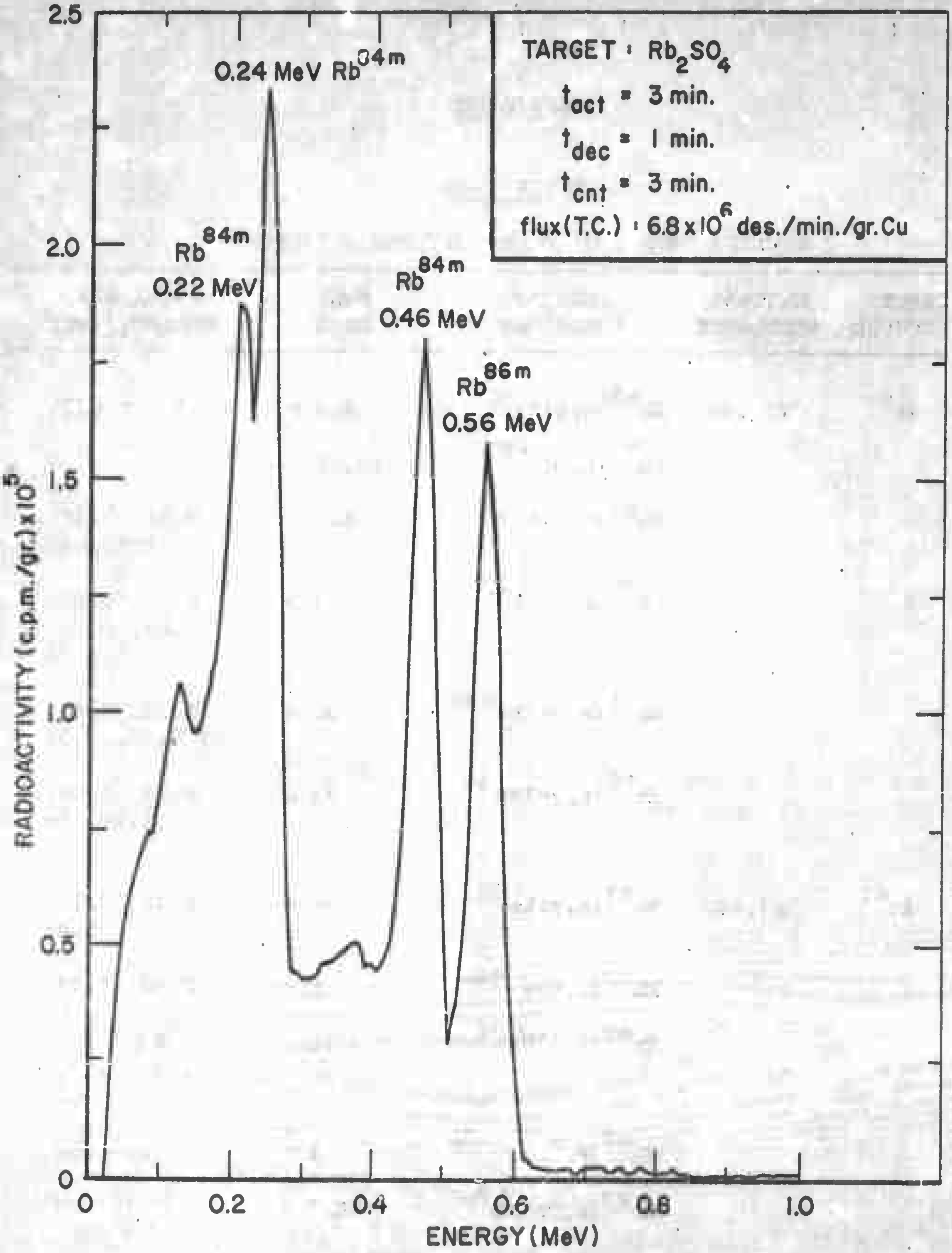

TARGET : Rb_2SO_4
t_{act} = 3 min.
t_{dec} = 1 min.
t_{cnt} = 3 min.
flux(T.C.) : 6.8×10^6 des./min./gr.Cu
0.24 MeV Rb^{84m}
Rb^{84m}
0.22 MeV
Rb^{84m}
0.46 MeV
Rb^{86m}
0.56 MeV
RADIOACTIVITY (c.p.m./gr.) x 10^5
2.5
2.0
1.5
1.0
0.5
0
0
0.2
0.4
0.6
0.8
1.0
ENERGY (MeV)

FIGURE I-Rb

TABLE II-Rb

PEAKS OBSERVED IN FIGURE I-Rb

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Rb	0.22	$Rb^{85}(n,2n)Rb^{84m}$	20 m	
	0.24	$Rb^{85}(n,2n)Rb^{84m}$	20 m	
	0.46	$Rb^{85}(n,2n)Rb^{84m}$	20 m	
	0.56	$Rb^{87}(n,2n)Rb^{86m}$	1 m	

NOTE: An irradiation and counting time of 5 minutes will change the ratio of the 0.46 Mev to 0.56 Mev photopeak.

TABLE III-Rb

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.46	3 m	1 m	3 m	458	0.33
0.56	3 m	1 m	3 m	490	0.29
0.22+0.24	5 m	1 m	5 m	2000	0.11
0.46	5 m	1 m	5 m	1490	0.12
0.56	5 m	1 m	5 m	635	0.21

TABLE IV-Rb

POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.56	Strontium	$Sr^{86}(n,p)Rb^{86m}$	

RUTHENIUM

TABLE I - Ru

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Ru^{96}	5.51%	$Ru^{96}(n,\alpha)Mo^{93m}$	6.9 h	0.69, 1.48, IT 0.26
		$Ru^{96}(n,\alpha)Mo^{93}$	$\approx 10^{4}$ y	
		$Ru^{96}(n,p)Tc^{96m}$	52 m	IT 0.034
		$Ru^{96}(n,p)Tc^{96}$	4.3 d	0.77, 0.84, 0.81, 1.12
		$Ru^{96}(n,2n)Ru^{95}$	99 m	0.34, 1.1, 0.63, $\beta+$
Ru^{98}	1.87%	$Ru^{98}(n,p)Tc^{98}$	$1.5x10^{6}$y	0.75, 0.66
		$Ru^{98}(n,2n)Ru^{97}$	2.9 d	0.22, 0.11, 0.57
Ru^{99}	12.72%	$Ru^{99}(n,p)Tc^{99m}$	6.0 h	0.140, IT 0.002, 0.142
		$Ru^{99}(n,p)Tc^{99}$	$2.1x10^{5}$y	
Ru^{100}	12.62%	$Ru^{100}(n,p)Tc^{100}$	17 s	0.54, 0.59
Ru^{101}	17.07%	$Ru^{101}(n,p)Tc^{101}$	14 m	0.31, 0.54, 0.13, 0.94
Ru^{102}	31.61%	$Ru^{102}(n,\alpha)Mo^{99}$	66 h	0.140, 0.74, 0.041, 0.78

TABLE I - Ru (Cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
		$Ru^{102}(n,p)Tc^{102m}$	4.5 m	0.47, 2.0
		$Ru^{102}(n,p)Tc^{102}$	5 s	
Ru^{104}	18.58%	$Ru^{104}(n,\alpha)Mo^{101}$	14.6m	1.02, 0.59, 2.08, 0.08, 1.66
		$Ru^{104}(n,p)Tc^{104}$	18 m	0.31, 4.8
		$Ru^{104}(n,2n)Ru^{103}$	40 d	0.040, 0.50, 0.05, 0.61

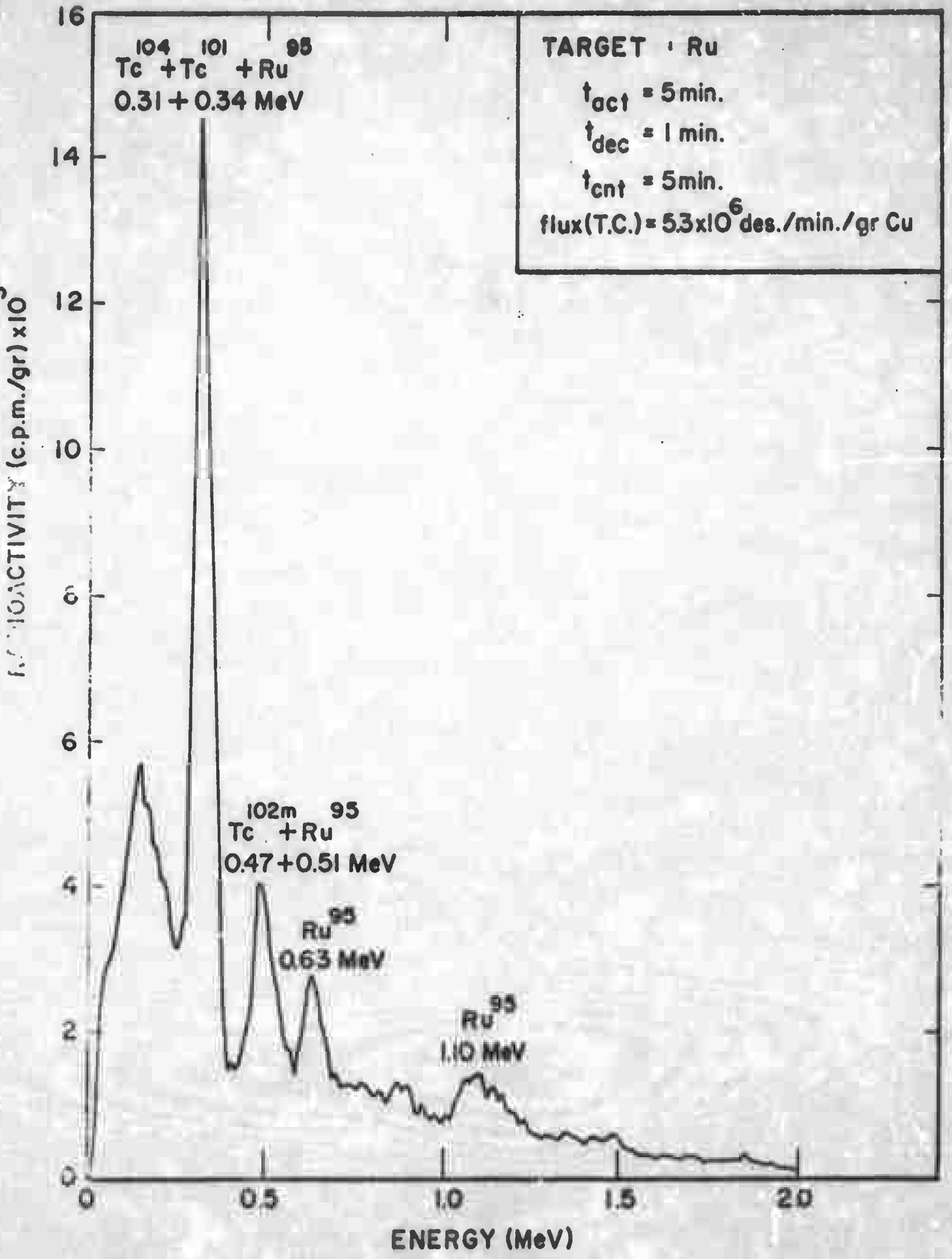

TARGET : Ru
t act = 5 min.
t dec = 1 min.
t cnt = 5 min.
flux(T.C.) = 5.3x10 6 des./min./gr Cu
Tc 104 + Tc 101 + Ru 95
0.31 + 0.34 MeV
Tc 102m + Ru 95
0.47 + 0.51 MeV
Ru 95
0.63 MeV
Ru 95
1.10 MeV
RADIOACTIVITY (c.p.m./gr) x10 3
ENERGY (MeV)
0
2
4
6
8
10
12
14
16
0.5
1.0
1.5
2.0

FIGURE I-Ru

TABLE II-Ru

PEAKS OBSERVED IN FIGURE I-Ru

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Ru	0.31 + 0.34	$Ru^{101}(n,p)Tc^{101}$	14 m	
		$Ru^{104}(n,p)Tc^{104}$	18 m	
		$Ru^{96}(n,2n)Ru^{95}$	99 m	
	0.47 + 0.51	$Ru^{102}(n,p)Tc^{102m}$	4.5 m	
		$Ru^{96}(n,2n)Ru^{95}$	99 m	
	0.63	$Ru^{96}(n,2n)Ru^{95}$	99 m	
	1.1	$Ru^{96}(n,2n)Ru^{95}$	99 m	

TABLE III-Ru

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/ mg/T_{cnt}	DETECTION LIMIT, mg
0.31	5 m	1 m	5 m	77	1.4

TABLE IV-Ru

POSSIBLE INTERFERING REACTIONS

No detectable interferences could be derived for ruthenium from any other element.

SAMARIUM

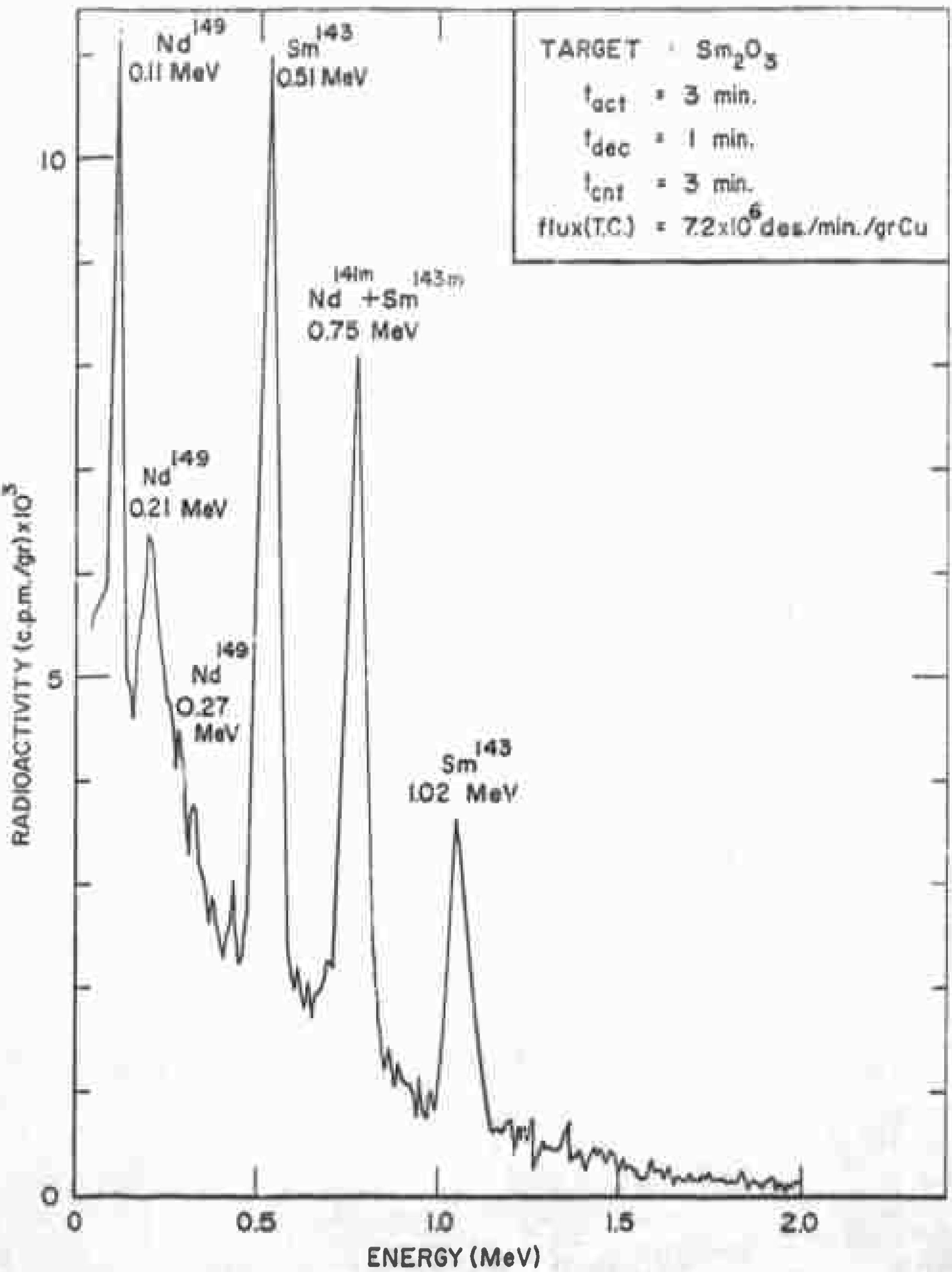
TABLE I-Sm

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Sm^{144}	3.09%	$Sm^{144}(n,p)Pm^{144}$	365 d	0.70, 0.62, 0.48
		$Sm^{144}(n,\alpha)Nd^{141m}$	64 s	IT 0.76
		$Sm^{144}(n,\alpha)Nd^{141}$	2.5 h	1.15, 1.30, β+
		$Sm^{144}(n,2n)Sm^{143m}$	1.0 m	IT 0.75
		$Sm^{144}(n,2n)Sm^{143}$	9.0 m	β+
Sm^{147}	14.97%	$Sm^{147}(n,p)Pm^{147}$	2.7 y	0.12
		$Sm^{147}(n,2n)Sm^{146}$	1.2×10^{8}y	
Sm^{148}	11.24%	$Sm^{148}(n,p)Pm^{148m}$	41 d	0.08, 1.0, IT 0.06
		$Sm^{148}(n,p)Pm^{148}$	5.4 d	0.55, 0.91, 1.46
Sm^{149}	13.83%	$Sm^{149}(n,p)Pm^{149}$	53 h	0.28, 0.85
Sm^{150}	7.44%	$Sm^{150}(n,p)Pm^{150}$	2.7 h	0.33, 1.17, 1.33, 0.83, 1.75, 0.41, 3.1
		$Sm^{150}(n,\alpha)Nd^{147}$	11.1 d	0.091, 0.53, 0.12, 0.69

TABLE I-Sm (cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Sm^{152}	26.72%	$Sm^{152}(n,p)Pm^{152}$	6 m	0.12, 0.24, 1.0
		$Sm^{152}(n,\alpha)Nd^{149}$	1.8 h	0.21, 0.27, 0.11, 0.65
		$Sm^{152}(n,2n)Sm^{151}$	90 y	0.022
Sm^{154}	22.71%	$Sm^{154}(n,p)Pm^{154}$	2.5 m	
		$Sm^{154}(n,\alpha)Nd^{151}$	12 m	0.12, 0.26, 0.030, 2.2
		$Sm^{154}(n,2n)Sm^{153}$	47 h	0.103, 0.07, 0.02, 0.64



TARGET : Sm_2O_3
t_{act} = 3 min.
t_{dec} = 1 min.
t_{cnt} = 3 min.
flux(T.C.) = 7.2×10^6 des./min./grCu
Nd^{149} 0.11 MeV
Sm^{143} 0.51 MeV
Nd^{141m} + Sm^{143m} 0.75 MeV
Nd^{149} 0.21 MeV
Nd^{149} 0.27 MeV
Sm^{143} 1.02 MeV
RADIOACTIVITY (c.p.m./gr) x 10^3
ENERGY (MeV)
0
5
10
0.5
1.0
1.5
2.0

FIGURE I-Sm

TABLE II-Sm

PEAKS OBSERVED IN FIGURE I-Sm

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Sm	0.11	$Sm^{152}(n,\alpha)Nd^{149}$	1.8 h	
	0.21	$Sm^{152}(n,\alpha)Nd^{149}$	1.8 h	
	0.27	$Sm^{152}(n,\alpha)Nd^{149}$	1.8 h	
	0.51	$Sm^{144}(n,2n)Sm^{143}$	9 m	
	0.75	$Sm^{144}(n,\alpha)Nd^{141m}$	64 s	
		$Sm^{144}(n,2n)Sm^{143m}$	1 m	
	1.02	$Sm^{144}(n,2n)Sm^{143}$	9 m	0.51 Mev coincidence sum peak

TABLE III-Sm

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.75	3 m	1 m	3 m	43	2.3
0.51	5 m	1 m	5 m	80	2.1
0.75	5 m	1 m	5 m	51	2.2

TABLE IV-Sm

POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.75	Cerium	$Ce^{140}(n,2n)Ce^{139m}$	(1)
	Neodymium	$Nd^{142}(n,2n)Nd^{141m}$	(1)
	Neodymium	$Nd^{142}(n,\alpha)Ce^{139m}$	
0.51	Nitrogen	$N^{14}(n,2n)N^{13}$	(2)
	Copper	$Cu^{63}(n,2n)Cu^{62}$	(2)

(1) Ce^{139m} and Nd^{141m} have a half life respectively of 55 sec and 64 sec, making their identification from Sm^{143m} very difficult.

(2) N^{13} and Cu^{62} have a half life respectively of 9.96 and 9.9 min, making their identification from Sm^{143} very difficult for other positron emitting radioisotopes, see Section I, Appendix II.

SELENIUM

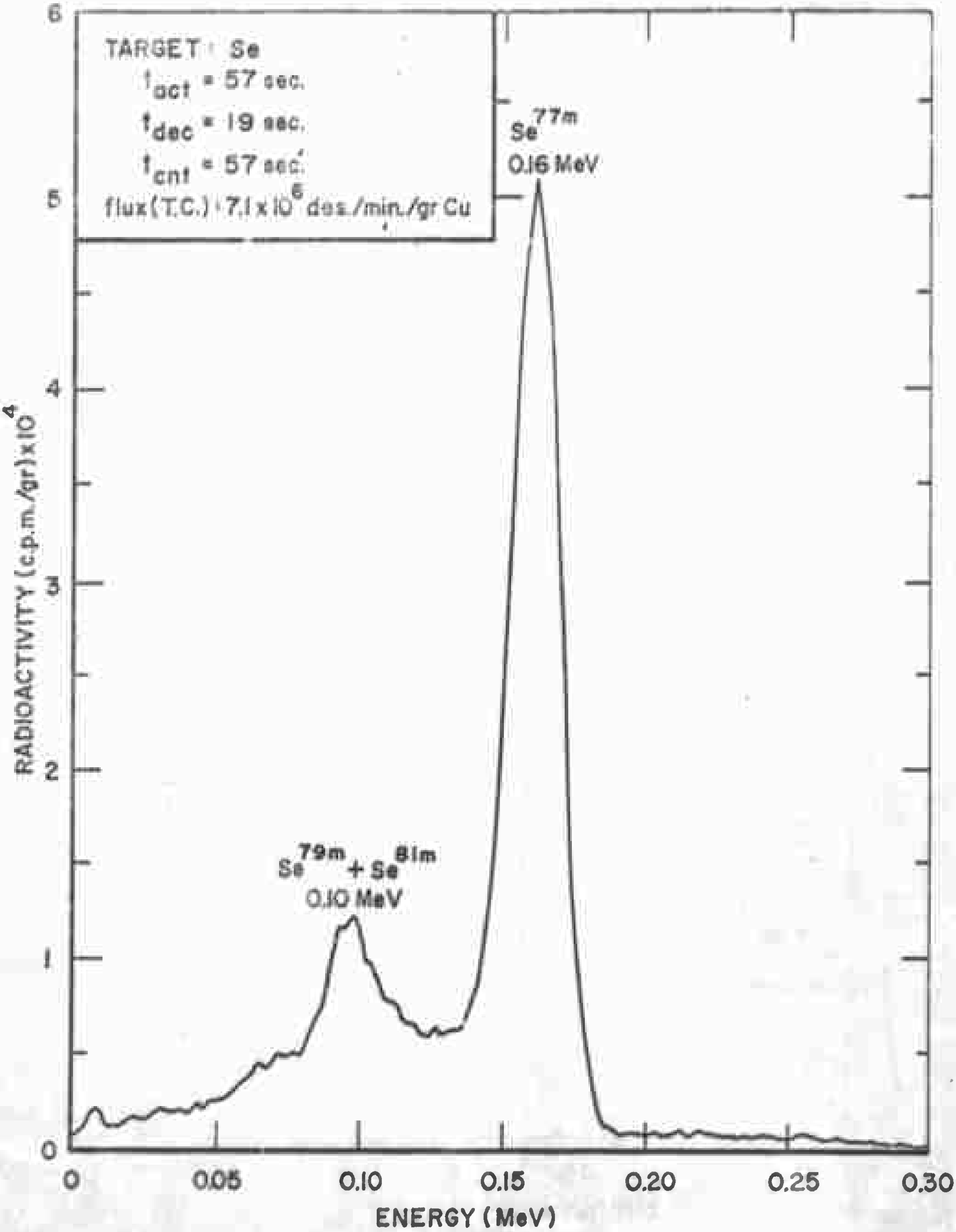
TABLE I-Se

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Se^{74}	0.87%	$Se^{74}(n,p)As^{74m}$	8 s	IT 0.28
		$Se^{74}(n,p)As^{74}$	18 d	0.60, 0.64, 2.52, β+
		$Se^{74}(n,\alpha)Ge^{71m}$	0.020 s	0.175, IT 0.023
		$Se^{74}(n,\alpha)Ge^{71}$	11 d	
		$Se^{74}(n,2n)Se^{73m}$	44 m	0.88, 0.25, 0.58, β+
		$Se^{74}(n,2n)Se^{73}$	7.1 h	0.36, 0.066, β+
Se^{76}	9.02%	$Se^{76}(n,p)As^{76}$	26.5 h	0.56, 1.21, 0.66, 0.64, 2.66
		$Se^{76}(n,\alpha)Ge^{73m}$	0.53 s	IT 0.054
		$Se^{76}(n,2n)Se^{75}$	120 d	0.265, 0.136, 0.280, 0.024, 0.58
Se^{77}	7.58%	$Se^{77}(n,p)As^{77m}$	116μs	IT 0.21
		$Se^{77}(n,p)As^{77}$	39 h	0.24, 0.52, 0.086, 0.160
		$Se^{77}(n,n')Se^{77m}$	18 s	IT 0.16

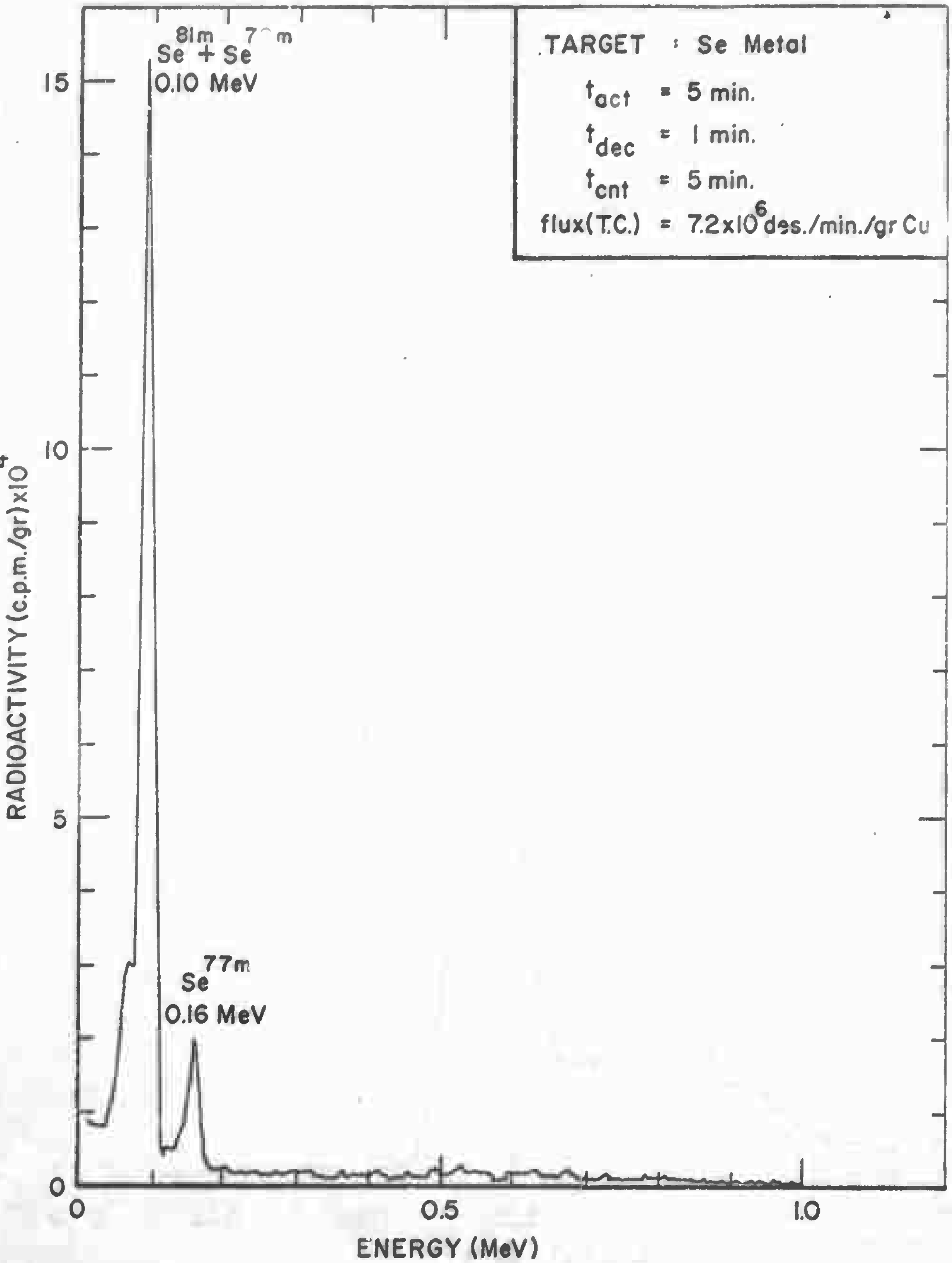
TABLE I-Se (cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Se^{78}	23.52%	$Se^{78}(n,p)As^{78m}$	6 m	IT 0.50
		$Se^{78}(n,p)As^{78}$	91 m	0.62, 0.70, 1.31, 0.08, 2.68
		$Se^{78}(n,\alpha)Ge^{75m}$	49 s	IT 0.14
		$Se^{78}(n,\alpha)Ge^{75}$	82 m	0.27, 0.07, 0.63
		$Se^{78}(n,2n)Se^{77m}$	18 s	IT 0.16
Se^{80}	49.82%	$Se^{80}(n,p)As^{80}$	15 s	0.66, 0.8, 2.35
		$Se^{80}(n,\alpha)Ge^{77m}$	54 s	0.159, IT 0.16
		$Se^{80}(n,\alpha)Ge^{77}$	11 h	0.22, 0.27, 0.04, 2.3
		$Se^{80}(n,2n)Se^{79m}$	3.9 m	IT 0.096
		$Se^{80}(n,2n)Se^{79}$	7×10^4y	
Se^{82}	9.19%	$Se^{82}(n,2n)Se^{81m}$	57 m	IT 0.10
		$Se^{82}(n,2n)Se^{81}$	18 m	0.28



TARGET : Se
t_{act} = 57 sec.
t_{dec} = 19 sec.
t_{cnt} = 57 sec.
flux (T.C.) : 7.1 x 10^6 dis./min./gr Cu
Se^{77m}
0.16 MeV
$Se^{79m} + Se^{81m}$
0.10 MeV
RADIOACTIVITY (c.p.m./gr) x 10^4
ENERGY (MeV)
0
1
2
3
4
5
6
0.05
0.10
0.15
0.20
0.25
0.30

FIGURE I-Se



81m
Se + Se
0.10 MeV
77m
Se
0.16 MeV
TARGET : Se Metal
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) = 7.2×10^6 des./min./gr Cu
RADIOACTIVITY (c.p.m./gr) x 10^4
15
10
5
0
0.5
1.0
ENERGY (MeV)

FIGURE II-Se

TABLE II-Se

PEAKS OBSERVED IN FIGURES I-Se and II-Se

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Se	0.10	$Se^{80}(n,2n)Se^{79m}$	3.9 m	
		$Se^{82}(n,2n)Se^{81m}$	57 m	
	0.16	$Se^{77}(n,n')Se^{77m}$	18 s	(1)
		$Se^{78}(n,2n)Se^{77m}$	18 s	
II-Se	0.10	$Se^{80}(n,2n)Se^{79m}$	3.9 m	
		$Se^{82}(n,2n)Se^{81m}$	57 m	
	0.16	$Se^{77}(n,n')Se^{77m}$	18 s	
		$Se^{78}(n,2n)Se^{77m}$	18 s	

(1) The decay curve made on the photopeak at 0.16 Mev does not show an activity due to Ge^{77m} ($T_{½}$ = 54 sec) produced by the $Se^{80}(n,\alpha)Ge^{77m}$ reaction.

NOTE: As^{74m} ($T_{½}$ = 8 sec) not detected for 24 sec irradiation, 8 sec decay and 24 sec counting time.

TABLE III-Se

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.16	57 s	19 s	57 s	261	0.44
0.16	5 m	1 m	5 m	56	1.7
0.10	5 m	1 m	5 m	496	0.24

TABLE IV-Se

POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for selenium from any other element.

SILICON

TABLE I - Si

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Si^{28}	92.21%	$Si^{28}(n,p)Al^{28}$	2.30m	1.78
		$Si^{28}(n,2n)Si^{27}$	4.2 s	0.84, 1.01 $\beta+$
Si^{29}	4.70%	$Si^{29}(n,p)Al^{29}$	6.6 m	1.28, 2.43
Si^{30}	3.09%	$Si^{30}(n,p)Al^{30}$	3.3 s	2.26, 3.52
		$Si^{30}(n,\alpha)Mg^{27}$	9.5 m	0.84, 1.01

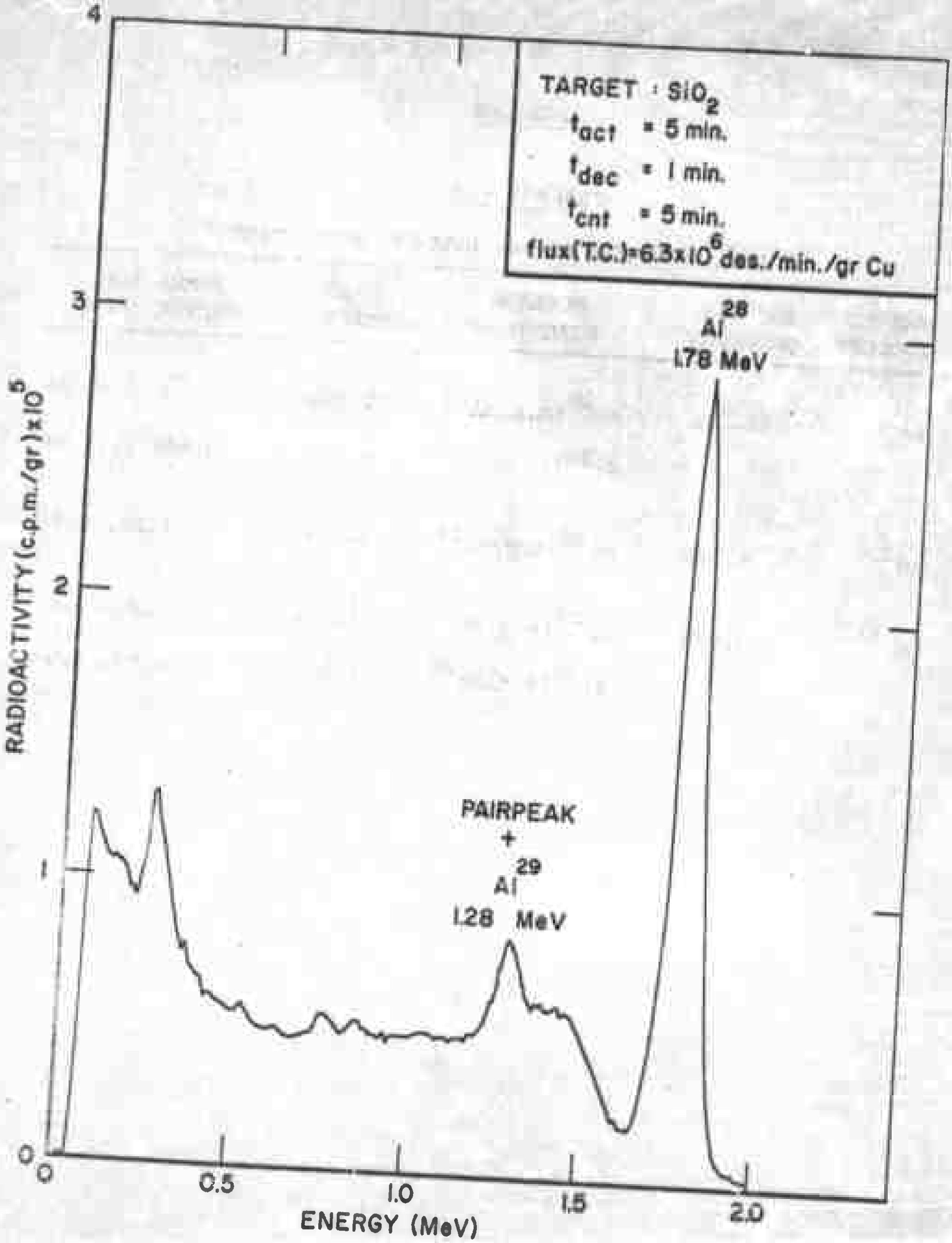

TARGET : SiO_2
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.)=6.3×10^6 des./min./gr Cu
Al^{28}
1.78 MeV
PAIRPEAK
+
Al^{29}
1.28 MeV
RADIOACTIVITY (c.p.m./gr) $\times10^5$
ENERGY (MeV)
0
0.5
1.0
1.5
2.0
1
2
3
4

FIGURE I-Si

TABLE II-Si

PEAKS OBSERVED IN FIGURE I-Si

FIGURE	GAMMA RAY ENERGY(Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Si	1.28	$Si^{29}(n,p)Al^{29}$	6.6 m	(1)
	1.78	$Si^{28}(n,p)Al^{28}$	2.30m	

(1) The photopeak at 1.27 Mev is a combination of the pair peak from 1.78 Mev and the photopeak due to Al^{29}. In this case, the largest contribution is from the Al^{29} isotope. This can be seen by comparing the spectra obtained from phosphorus and silicon. In the case of phosphorus, the 1.27 Mev photopeak is smaller than in the case for silicon.

NOTE: Al^{30} ($T_{\frac{1}{2}}$ = 3.3 sec) and Si^{27} ($T_{\frac{1}{2}}$ = 4.2 sec) not detected for 13 sec irradiation, 4 sec decay and 13 sec counting time.

TABLE III-Si

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	$COUNTS/mg/T_{cnt}$	DETECTION LIMIT(mg)
1.78	5 m	1 m	5 m	2360	0.07

SILICON

TABLE IV-Si

POSSIBLE INTERFERING REACTIONS

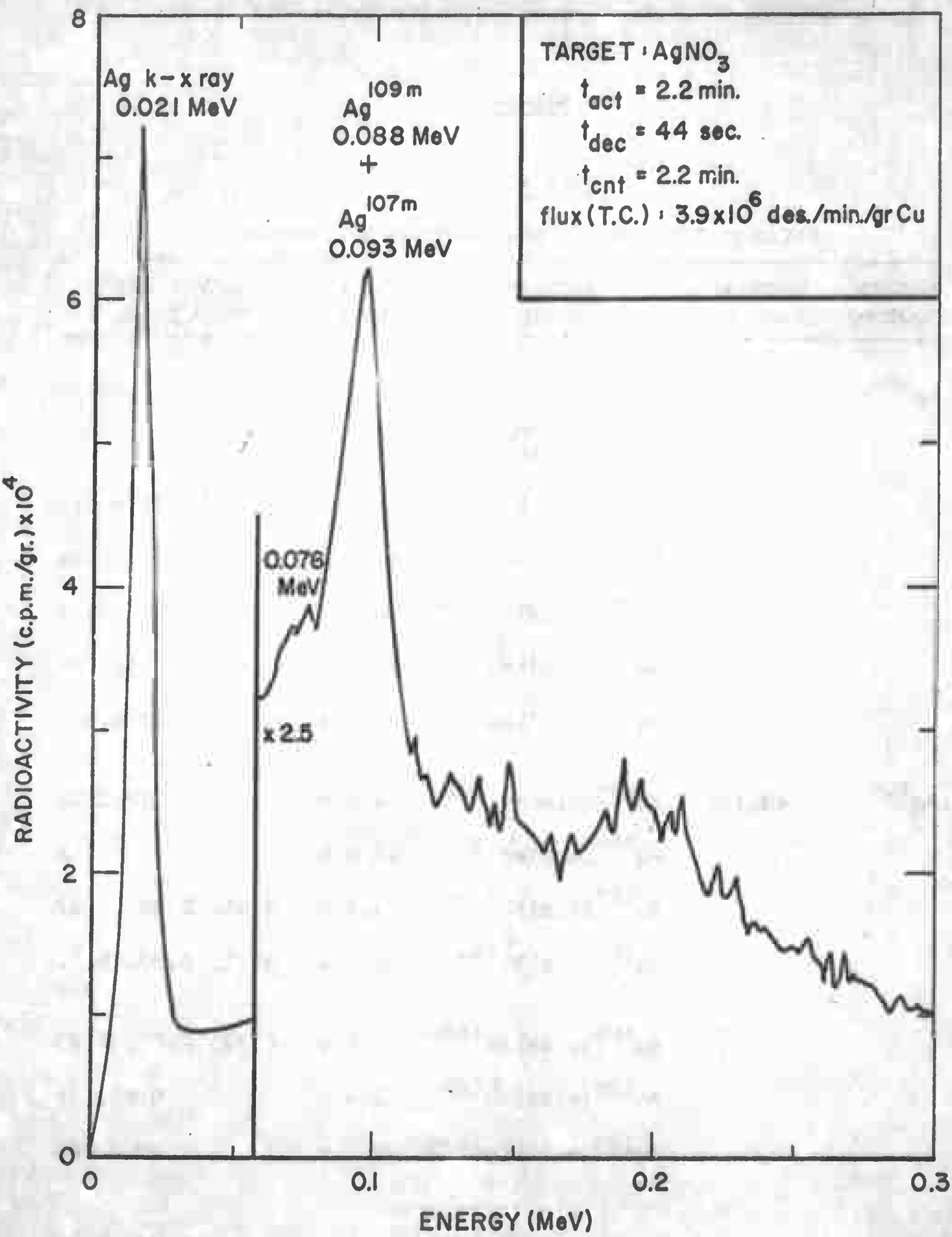
GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
1.78	Phosphorus	$P^{31}(n,\alpha)Al^{28}$	
	Aluminum	$Al^{27}(n,\gamma)Al^{28}$	

SILVER

TABLE I - Ag

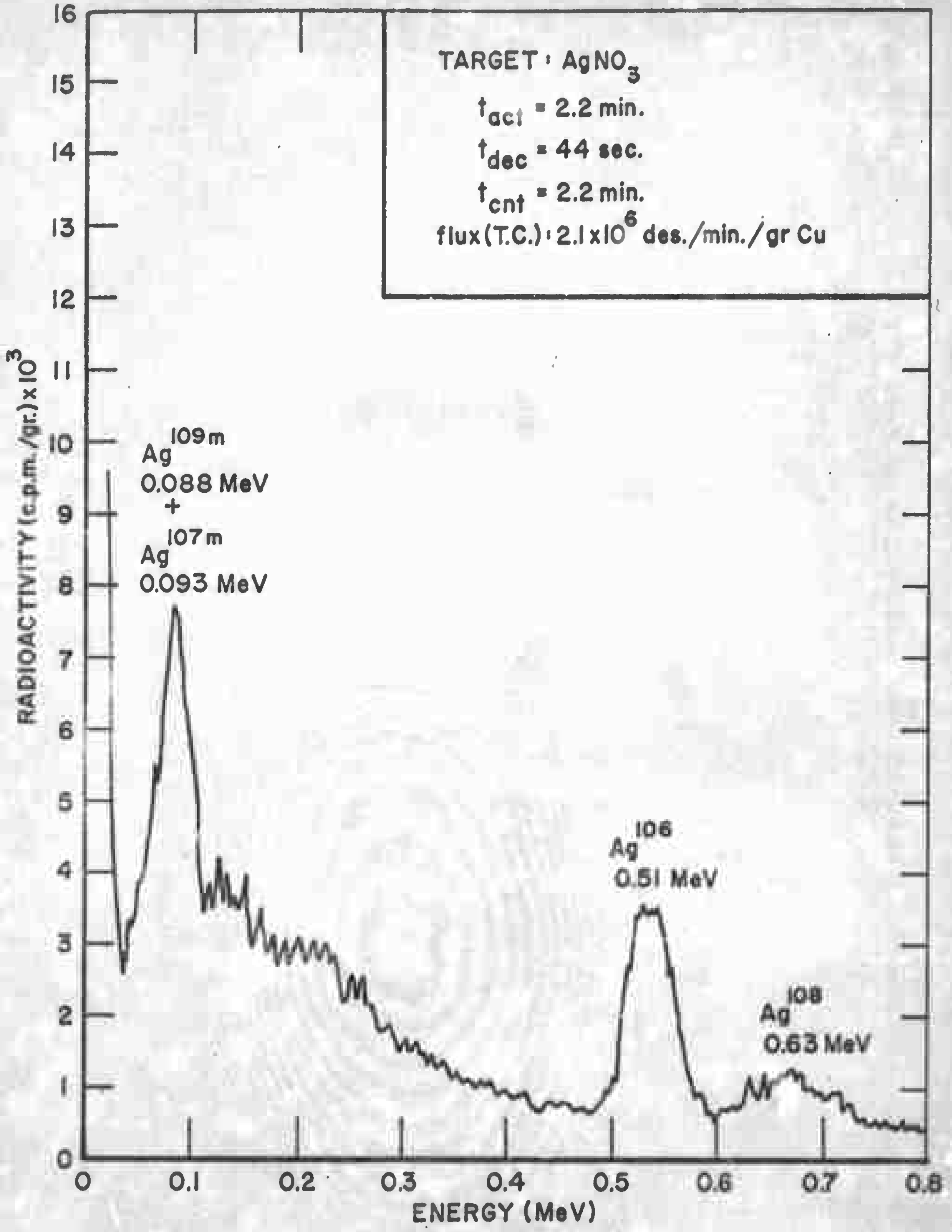
NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Ag^{107}	51.82%	$Ag^{107}(n,p)Pd^{107m}$	22 s	IT 0.22
		$Ag^{107}(n,p)Pd^{107}$	7×10^6y	
		$Ag^{107}(n,\alpha)Rh^{104m}$	4.4 m	0.051, IT 0.077
		$Ag^{107}(n,\alpha)Rh^{104}$	42 s	0.56, 1.24
		$Ag^{107}(n,2n)Ag^{106m}$	8.3 d	0.51, 2.63
		$Ag^{107}(n,2n)Ag^{106}$	24 m	0.51, β+
		$Ag^{107}(n,n')Ag^{107m}$	44 s	IT 0.093
Ag^{109}	48.18%	$Ag^{109}(n,p)Pd^{109m}$	4.8 m	IT 0.18
		$Ag^{109}(n,p)Pd^{109}$	13.5 h	0.088
		$Ag^{109}(n,\alpha)Rh^{106m}$	2.2 h	0.51, 0.22, 1.22
		$Ag^{109}(n,\alpha)Rh^{106}$	30 s	0.51, 0.62, 0.7, 3.4
		$Ag^{109}(n,2n)Ag^{108m}$	7.5 y	0.72, 0.62, 0.43
		$Ag^{109}(n,2n)Ag^{108}$	2.4 m	0.63, β+
		$Ag^{109}(n,n')Ag^{109m}$	40 s	IT 0.088



TARGET : $AgNO_3$
t_{act} = 2.2 min.
t_{dec} = 44 sec.
t_{cnt} = 2.2 min.
flux (T.C.) : 3.9×10^6 des./min./gr Cu
Ag k-x ray
0.021 MeV
Ag^{109m}
0.088 MeV
+
Ag^{107m}
0.093 MeV
0.076 MeV
x 2.5
RADIOACTIVITY (c.p.m./gr.) $\times 10^4$
ENERGY (MeV)
0
2
4
6
8
0
0.1
0.2
0.3

FIGURE I-Ag



TARGET : $AgNO_3$
t_{act} = 2.2 min.
t_{dec} = 44 sec.
t_{cnt} = 2.2 min.
flux (T.C.) : 2.1×10^6 des./min./gr Cu
Ag^{109m}
0.088 MeV
+
Ag^{107m}
0.093 MeV
Ag^{106}
0.51 MeV
Ag^{108}
0.63 MeV
RADIOACTIVITY (c.p.m./gr.) $\times 10^3$
ENERGY (MeV)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8

FIGURE II-Ag

TABLE II-Ag

PEAKS OBSERVED IN FIGURES I-Ag and II-Ag

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Ag	0.021			k-x ray Ag
	0.093	$Ag^{107}(n,n')Ag^{107m}$	44 s	
	0.088	$Ag^{109}(n,n')Ag^{109m}$	40 s	(1)
II-Ag	0.51	$Ag^{107}(n,2n)Ag^{106}$	24 m	(2)
	0.63	$Ag^{109}(n,2n)Ag^{108}$	2.4m	

(1) The actual energy observed is 0.076 Mev because of the relatively high activity due to the 0.093 Mev peak. Contribution from the ($Ag^{109}(n,p)Pd^{109}$) reaction is negligible and can be seen from the study of the decay curve of the 0.093 + 0.088 Mev γ energy peak combined.

(2) The sum peak at 1.02 Mev is not shown, in this figure.

TABLE III-Ag

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.093+0.088	2.2 m	44 s	2.2 m	146	2.2
0.021	2.2 m	44 s	2.2 m	316	0.40
0.51	5 m	1 m	5 m	2127	0.08

NOTE: The observation of the k-x ray is very much dependent upon sample shape and should only be used analytically where sample size and shape is controlled.

TABLE IV-Ag

POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for silver from any other element.

SODIUM

TABLE I - Na

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Na^{23}	100%	$Na^{23}(n,p)Ne^{23}$	38s	0.44 1.65
		$Na^{23}(n,\alpha)F^{20}$	11s	1.63
		$Na^{23}(n,2n)Na^{22}$	2.58y	1.28 $\beta+$

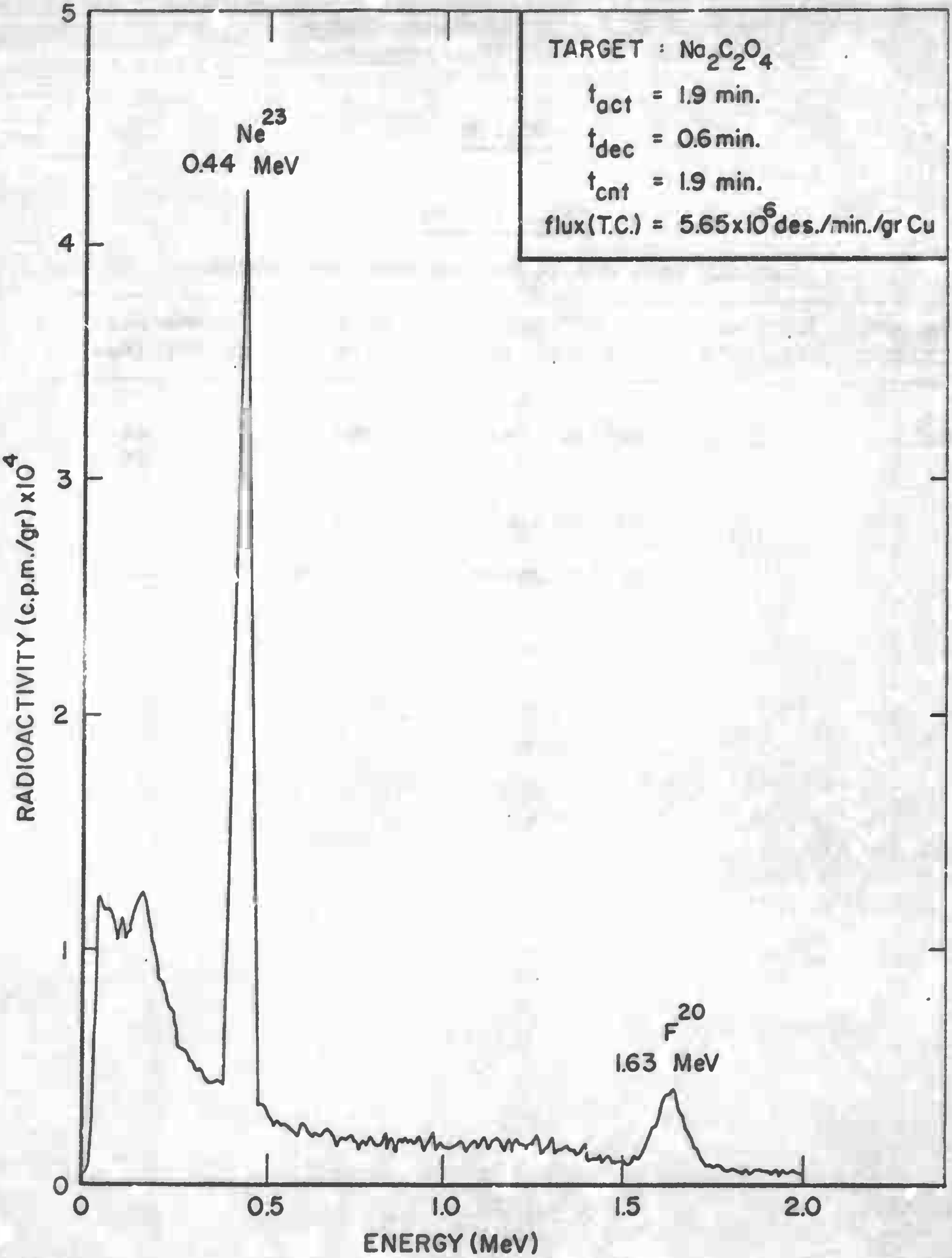

TARGET : $Na_2C_2O_4$
t_{act} = 1.9 min.
t_{dec} = 0.6 min.
t_{cnt} = 1.9 min.
flux(T.C.) = 5.65×10^6 des./min./gr Cu
Ne^{23}
0.44 MeV
F^{20}
1.63 MeV
RADIOACTIVITY (c.p.m./gr) $\times 10^4$
ENERGY (MeV)
0
1
2
3
4
5
0.5
1.0
1.5
2.0

FIGURE I-Na

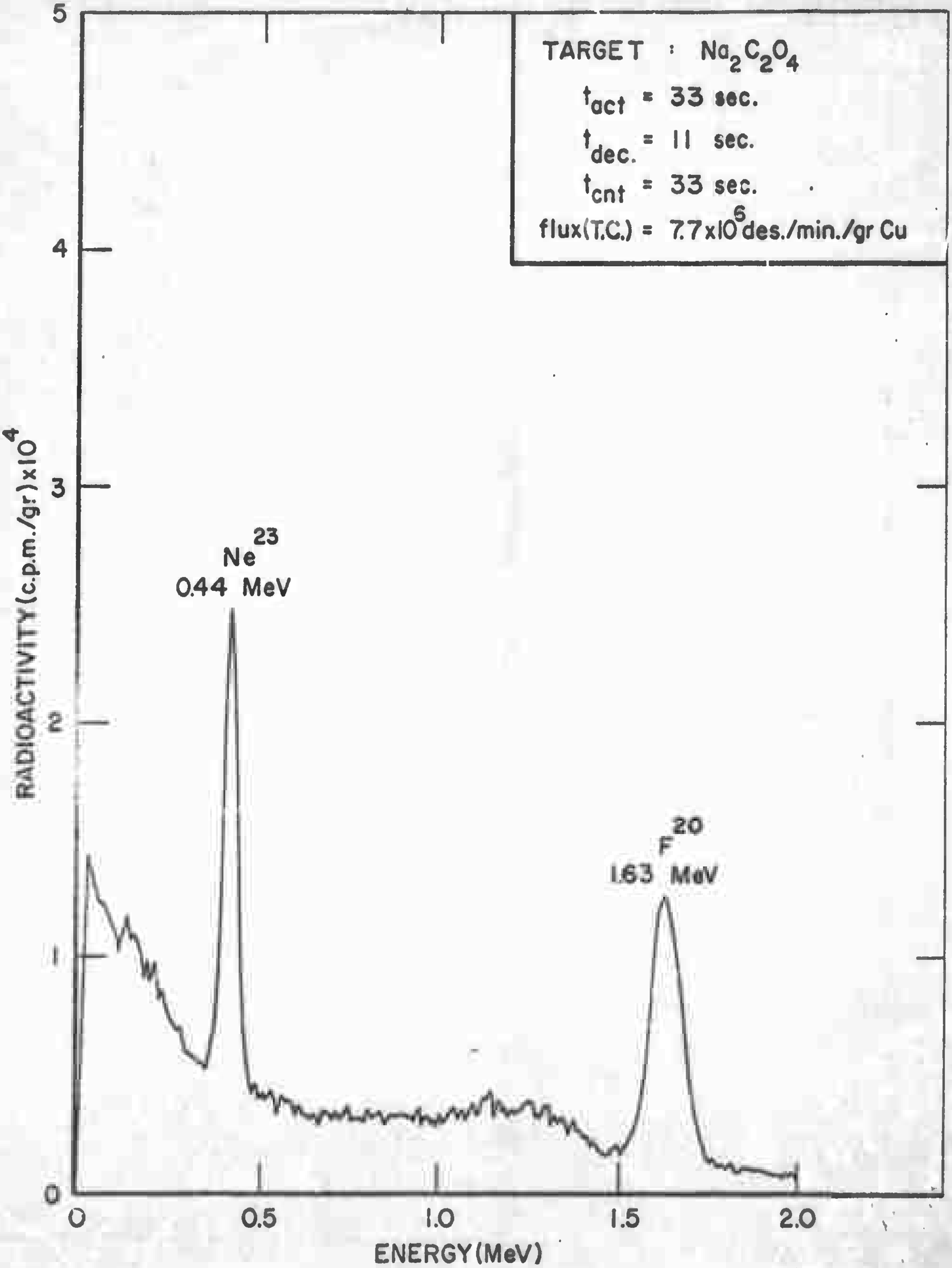

TARGET : $Na_2C_2O_4$
t_{act} = 33 sec.
$t_{dec.}$ = 11 sec.
t_{cnt} = 33 sec.
flux(T.C.) = 7.7×10^6 des./min./gr Cu
Ne^{23}
0.44 MeV
F^{20}
1.63 MeV
RADIOACTIVITY (c.p.m./gr.) $\times 10^4$
ENERGY (MeV)
0
1
2
3
4
5
0.5
1.0
1.5
2.0

FIGURE II-Na

TABLE II-Na

PEAKS OBSERVED IN FIGURE I-Na and II-Na

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Na	0.44	$Na^{23}(n,p)Ne^{23}$	38 s	
and II-Na	1.63	$Na^{23}(n,\alpha)F^{20}$	11 s	

TABLE III-Na

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.44	1.9 m	38 s	1.9 m	200	0.37
0.44	33 s	11 s	33 s	75	0.50
1.63	33 s	11 s	33 s	93	0.25

TABLE IV-Na

POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.44	Magnesium	$Mg^{26}(n,\alpha)Ne^{23}$	

STRONTIUM

TABLE I - Sr

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Sr^{84}	0.56%	$Sr^{84}(n,p)Rb^{84m}$	20 m	0.24, IT 0.22, 0.46
		$Sr^{84}(n,p)Rb^{84}$	33 d	0.88, 1.01, 1.90, $\beta+$
		$Sr^{84}(n,\alpha)Kr^{81m}$	13 s	IT 0.19
		$Sr^{84}(n,\alpha)Kr^{81}$	2.1×10^{5}y	
		$Sr^{84}(n,2n)Sr^{83}$	33 h	0.755, 0.385, 0.040, $\beta+$
Sr^{86}	9.86%	$Sr^{86}(n,p)Rb^{86m}$	1 m	IT 0.56
		$Sr^{86}(n,p)Rb^{86}$	18.7 d	1.08
		$Sr^{86}(n,\alpha)Kr^{83m}$	1.86h	0.009, IT 0.032
		$Sr^{86}(n,2n)Sr^{85m}$	70 m	0.23, IT 0.008, 0.23
		$Sr^{86}(n,2n)Sr^{85}$	64 d	0.514
Sr^{87}	7.02%	$Sr^{87}(n,n')Sr^{87m}$	2.8 h	IT 0.39
Sr^{88}	82.56%	$Sr^{88}(n,p)Rb^{88}$	18 m	1.85, 0.91, 2.7, 1.39, 4.9
		$Sr^{88}(n,\alpha)Kr^{85m}$	4.4 h	0.15, IT 0.31
		$Sr^{88}(n,\alpha)Kr^{85}$	10.76y	0.52
		$Sr^{88}(n,2n)Sr^{87m}$	2.8 h	IT 0.39

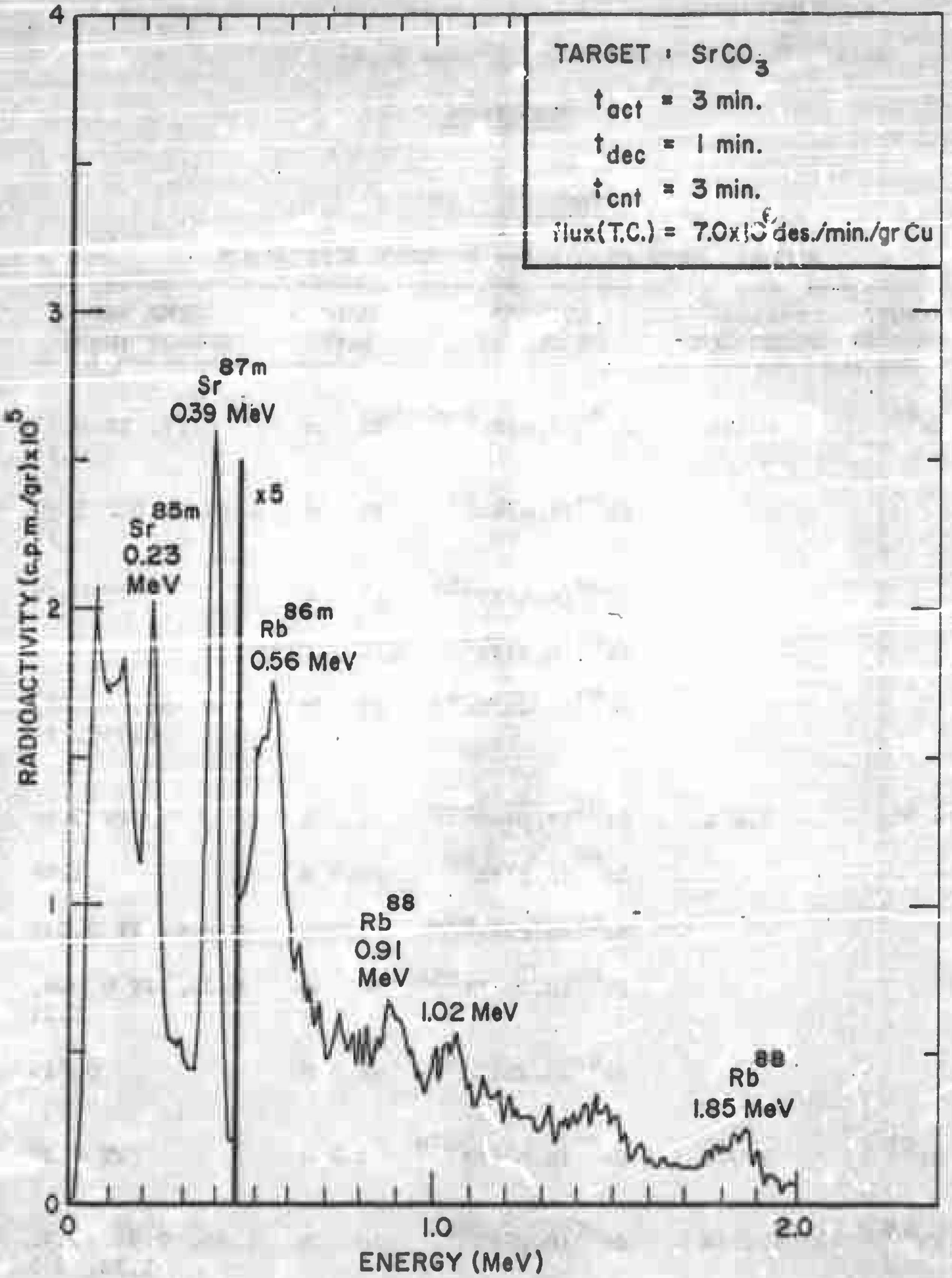

TARGET : $SrCO_3$
t_{act} = 3 min.
t_{dec} = 1 min.
t_{cnt} = 3 min.
flux(T.C.) = 7.0×10^6 des./min./gr Cu
RADIOACTIVITY (c.p.m./gr) x 10^5
ENERGY (MeV)
Sr^{85m} 0.23 MeV
Sr^{87m} 0.39 MeV
x5
Rb^{86m} 0.56 MeV
Rb^{88} 0.91 MeV
1.02 MeV
Rb^{88} 1.85 MeV

FIGURE I-Sr

TABLE II-Sr

PEAKS OBSERVED IN FIGURE I-Sr

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Sr	0.23	$Sr^{86}(n,2n)Sr^{85m}$	70 m	(1)
	0.39	$Sr^{88}(n,2n)Sr^{87m}$	2.8h	
		$Sr^{87}(n,n')Sr^{87m}$	2.8h	
	0.51 + 0.56	$Sr^{86}(n,p)Rb^{86m}$	1 m	(2)
	0.91	$Sr^{88}(n,p)Rb^{88}$	18 m	
	1.85	$Sr^{88}(n,p)Rb^{88}$	18 m	

(1) By following the decay of the 0.23 Mev photopeak, no contribution, due to Rb^{84m} ($T_{1/2}$ = 20 min), has been found.

(2) Photopeak at 0.56 Mev is a combination of the activity at 0.56 Mev from Rb^{86m} and the activity at 0.51 Mev from the N^{13} of the vial.

NOTE: Kr^{81m} ($T_{1/2}$ = 13 sec) not detected for 39 sec irradiation, 13 sec decay and 39 sec counting time.

TABLE III-Sr

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.23	5 m	1 m	5 m	63	1.8
0.39	5 m	1 m	5 m	198	0.80

NOTE: The determination of Sr, using the 0.56 Mev photopeak, is not reliable because of the activity at 0.51 Mev due to N^{13} produced in the vial.

STRONTIUM

TABLE IV-Sr

POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for strontium from any other element.

TANTALUM

TABLE I - Ta

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Ta^{180}	0.0123%	$Ta^{180}(n,p)Hf^{180m}$	5.5 h	0.093, 0.44, IT 0.058, -0.50
		$Ta^{180}(n,\alpha)Lu^{177m}$	155 d	0.055, 0.47, IT 0.12
		$Ta^{180}(n,\alpha)Lu^{177}$	6.8 d	0.208, 0.113, 0.07, 0.32
		$Ta^{180}(n,2n)Ta^{179}$	~1.6 y	
		$Ta^{180}(n,n')Ta^{180m}$	8.1 h	0.093, 0.102
Ta^{181}	99.988%	$Ta^{181}(n,p)Hf^{181}$	45 d	0.48, 0.006, 0.70
		$Ta^{181}(n,\alpha)Lu^{178m}$	30 m	0.089, 0.093, 0.43
		$Ta^{181}(n,\alpha)Lu^{178}$	5 m	0.33, 0.089, 0.093, 0.43
		$Ta^{181}(n,2n)Ta^{180m}$	8.1 h	0.093, 0.102
		$Ta^{181}(n,n')Ta^{181m}$	20 µs	
		$Ta^{181}(n,n')Ta^{181m}$	7 µs	IT 0.006

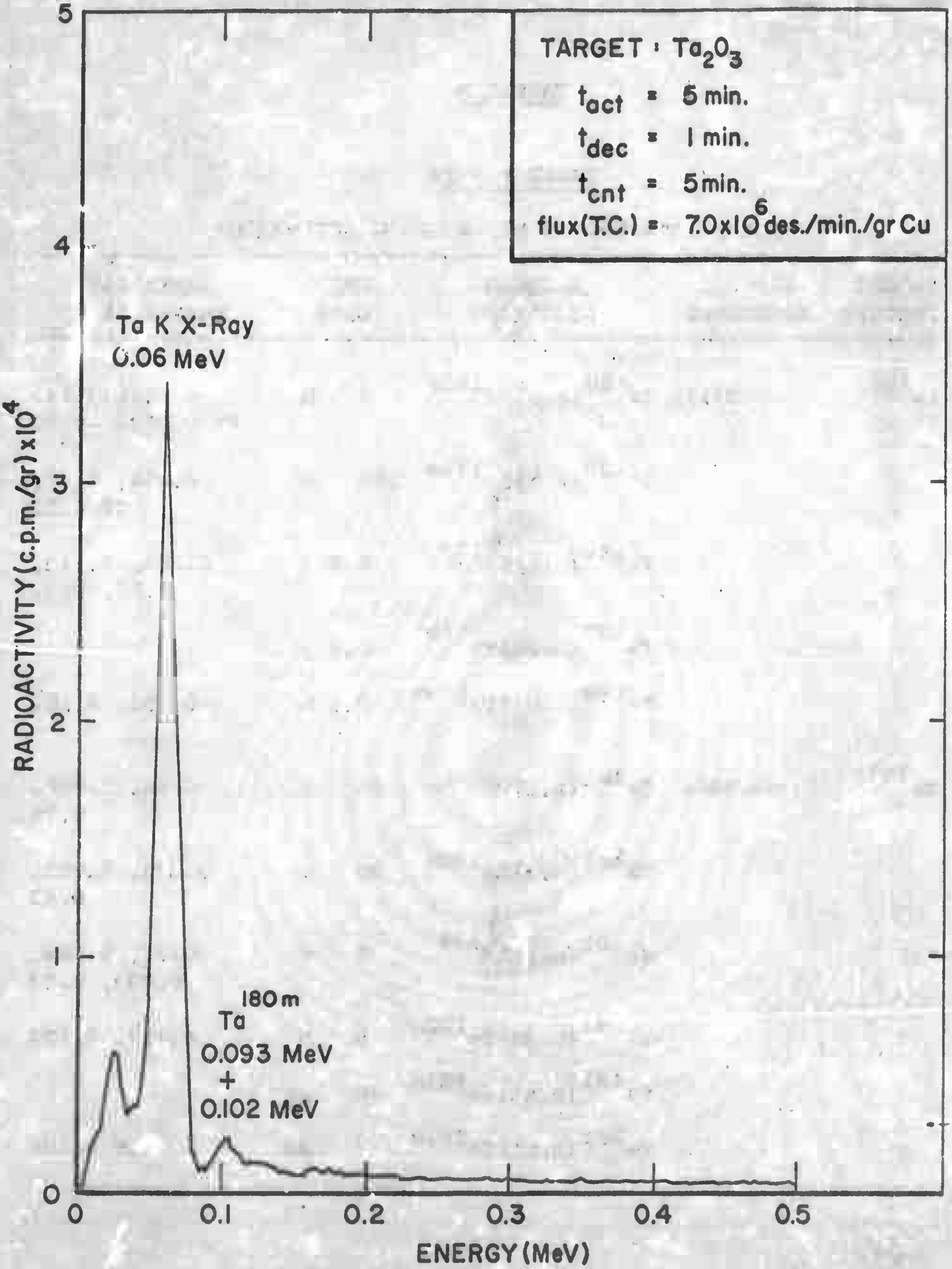

TARGET : Ta_2O_3
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) = 7.0×10^6 des./min./gr Cu
Ta K X-Ray
0.06 MeV
Ta^{180m}
0.093 MeV
+
0.102 MeV
RADIOACTIVITY (c.p.m./gr) $\times 10^4$
ENERGY (MeV)
0
1
2
3
4
5
0.1
0.2
0.3
0.4
0.5

FIGURE I-Ta

TABLE II-Ta

PEAKS OBSERVED IN FIGURE I-Ta

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Ta	0.06			Ta x-ray
	0.093	$Ta^{180}(n,n')Ta^{180m}$	8.1 h	
	0.102	$Ta^{181}(n,2n)Ta^{180m}$	8.1 h	

TABLE III-Ta

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.06	5 m	1 m	5 m	165	0.48

TABLE IV-Ta

POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for tantalum from any other element.

TERBIUM

TABLE I - Tb

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Tb^{159}	100%	$Tb^{159}(n,p)Gd^{159}$	18 h	0.058, 0.36
		$Tb^{159}(n,\alpha)Eu^{156}$	15.2d	0.089, 1.23, 0.20, 2.19
		$Tb^{159}(n,2n)Tb^{158m}$	11 s	IT 0.111
		$Tb^{159}(n,2n)Tb^{158}$	150 y	0.08, 1.19

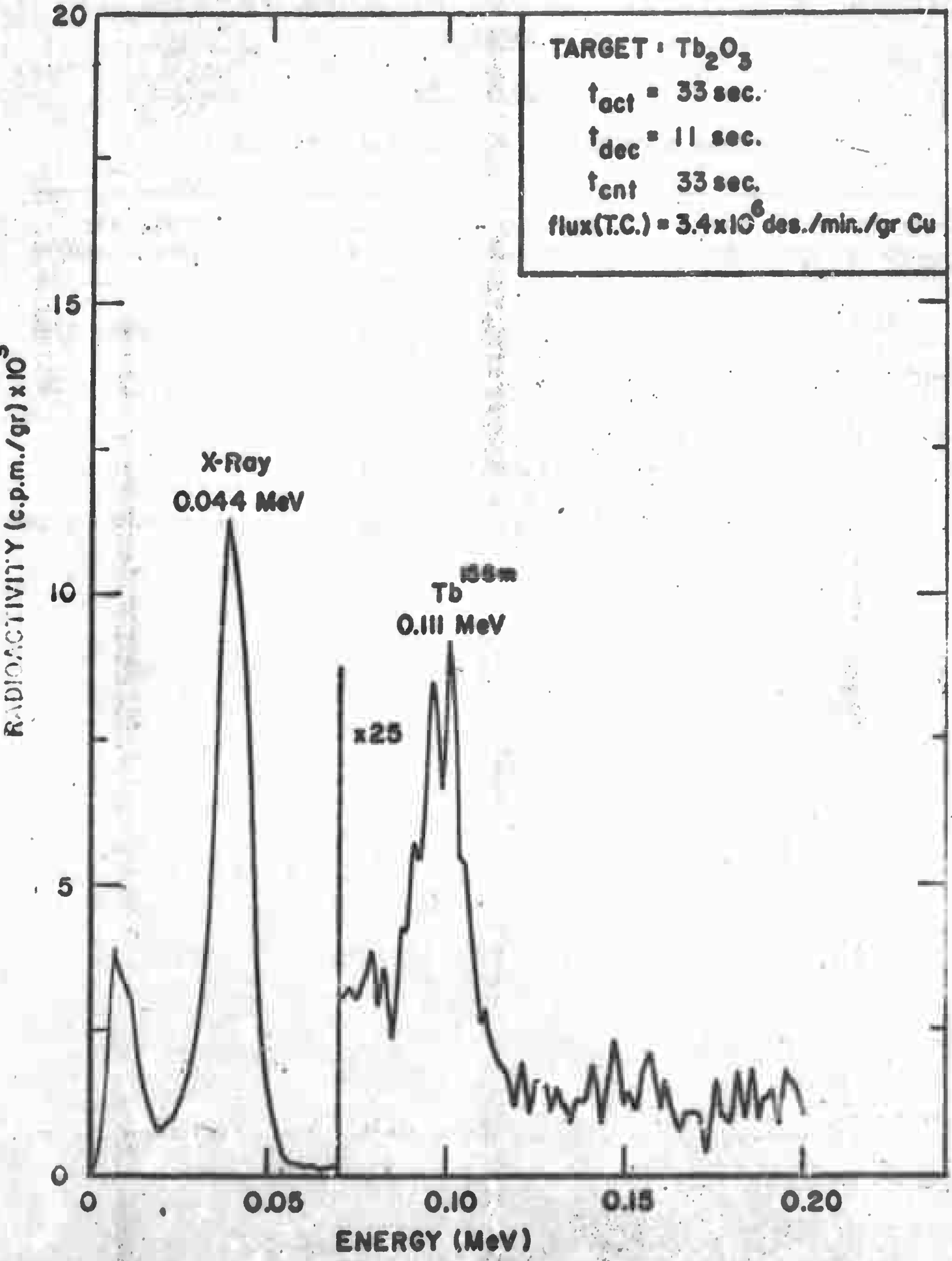

TARGET : Tb_2O_3
t_{act} = 33 sec.
t_{dec} = 11 sec.
t_{cnt} 33 sec.
flux(T.C.) = 3.4×10^6 des./min./gr Cu
X-Ray
0.044 MeV
Tb^{158m}
0.111 MeV
x25
RADIOACTIVITY (c.p.m./gr) x 10^3
ENERGY (MeV)
0
5
10
15
20
0
0.05
0.10
0.15
0.20

FIGURE I-Tb

TABLE II - Tb

PEAKS OBSERVED IN FIGURE I - Tb

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Tb	0.044			x-rays
	0.111	$Tb^{159}(n,2n)Tb^{158m}$	11 s	

TABLE III - Tb

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/ mg/T_{cnt}	DETECTION LIMIT, mg
0.044	33 s	11 s	33 s	123	0.93

TABLE IV - Tb

POSSIBLE INTERFERING REACTIONS

No detectable interferences could be derived for terbium from any other element.

TIN

TABLE I - Sn

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Sn^{112}	0.96%	$Sn^{112}(n,p)In^{112m}$	0.042s	IT 0.31
		$Sn^{112}(n,p)In^{112m}$	21m	IT 0.155
		$Sn^{112}(n,p)In^{112}$	14m	0.62, 0.71, β+
		$Sn^{112}(n,\alpha)Cd^{109m}$	12μs	IT 0.058
		$Sn^{112}(n,\alpha)Cd^{109}$	1.3y	0.088
		$Sn^{112}(n,2n)Sn^{111}$	35m	β+
Sn^{114}	0.66%	$Sn^{114}(n,p)In^{114m}$	2.5 s	IT 0.150
		$Sn^{114}(n,p)In^{114m}$	50d	0.72, 0.56, IT 0.191
		$Sn^{114}(n,p)In^{114}$	72s	β+
		$Sn^{114}(n,\alpha)Cd^{111m}$	49m	0.247, IT 0.15
		$Sn^{114}(n,2n)Sn^{113}$	20m	IT 0.079
		$Sn^{114}(n,2n)Sn^{113}$	118d	0.255, 0.39
Sn^{115}	0.35%	$Sn^{115}(n,p)In^{115m}$	4.4h	IT 0.34
		$Sn^{115}(n,n')Sn^{115m}$	159μs	0.12, 0.50, IT 0.11
Sn^{116}	14.30%	$Sn^{116}(n,p)In^{116m}$	2.2 s	IT 0.16
		$Sn^{116}(n,p)In^{116m}$	54m	1.29, 1.10

TABLE I - Sn (Cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
		$Sn^{116}(n,p)In^{116}$	14s	1.3
		$Sn^{116}(n,\alpha)Cd^{113}$	14y	IT 0.27
		$Sn^{116}(n,2n)Sn^{115m}$	159μs	0.12, 0.50, IT 0.11
Sn^{117}	7.61%	$Sn^{117}(n,p)In^{117m}$	1.9h	0.16, IT 0.31
		$Sn^{117}(n,p)In^{117}$	45m	0.56, 0.16
		$Sn^{117}(n,n')Sn^{117m}$	14d	0.161, IT 0.159
Sn^{118}	24.03%	$Sn^{118}(n,p)In^{118m}$	4.4m	1.22, 1.05, 0.2, 2.0
		$Sn^{118}(n,p)In^{118}$	5.1s	1.22
		$Sn^{118}(n,\alpha)Cd^{115m}$	43d	0.94, 0.17, 1.56
		$Sn^{118}(n,\alpha)Cd^{115}$	2.3d	0.52, 0.34
		$Sn^{118}(n,n')Sn^{117m}$	14d	0.161, IT 0.159
Sn^{119}	8.58%	$Sn^{119}(n,p)In^{119m}$	18m	0.9, IT 0.3
		$Sn^{119}(n,p)In^{119}$	2.0m	0.82
		$Sn^{119}(n,n')Sn^{119m}$	250d	0.024, IT 0.065
Sn^{120}	32.85%	$Sn^{120}(n,p)In^{120m}$	3.2s	1.18
		$Sn^{120}(n,p)In^{120}$	44s	0.73, 1.18
		$Sn^{120}(n,\alpha)Cd^{117m}$	3.2h	0.3, 2.5
		$Sn^{120}(n,\alpha)Cd^{117}$	2.5h	0.3, 1.6

TABLE I - Sn (Cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
		$Sn^{120}(n,2n)Sn^{119}$	250 d	0.024, IT 0.065
Sn^{122}	4.72%	$Sn^{122}(n,p)In^{122}$	7.5 s	1.14 1.0
		$Sn^{122}(n,\alpha)Cd^{119m}$	2.7 m	
		$Sn^{122}(n,\alpha)Cd^{119}$	9.5 m	0.82
		$Sn^{122}(n,2n)Sn^{121m}$	≈25 y	0.037
		$Sn^{122}(n,2n)Sn^{121}$	27 y	
Sn^{124}	5.94%	$Sn^{124}(n,2n)Sn^{123m}$	125 d	1.08
		$Sn^{124}(n,2n)Sn^{123}$	40 m	0.16

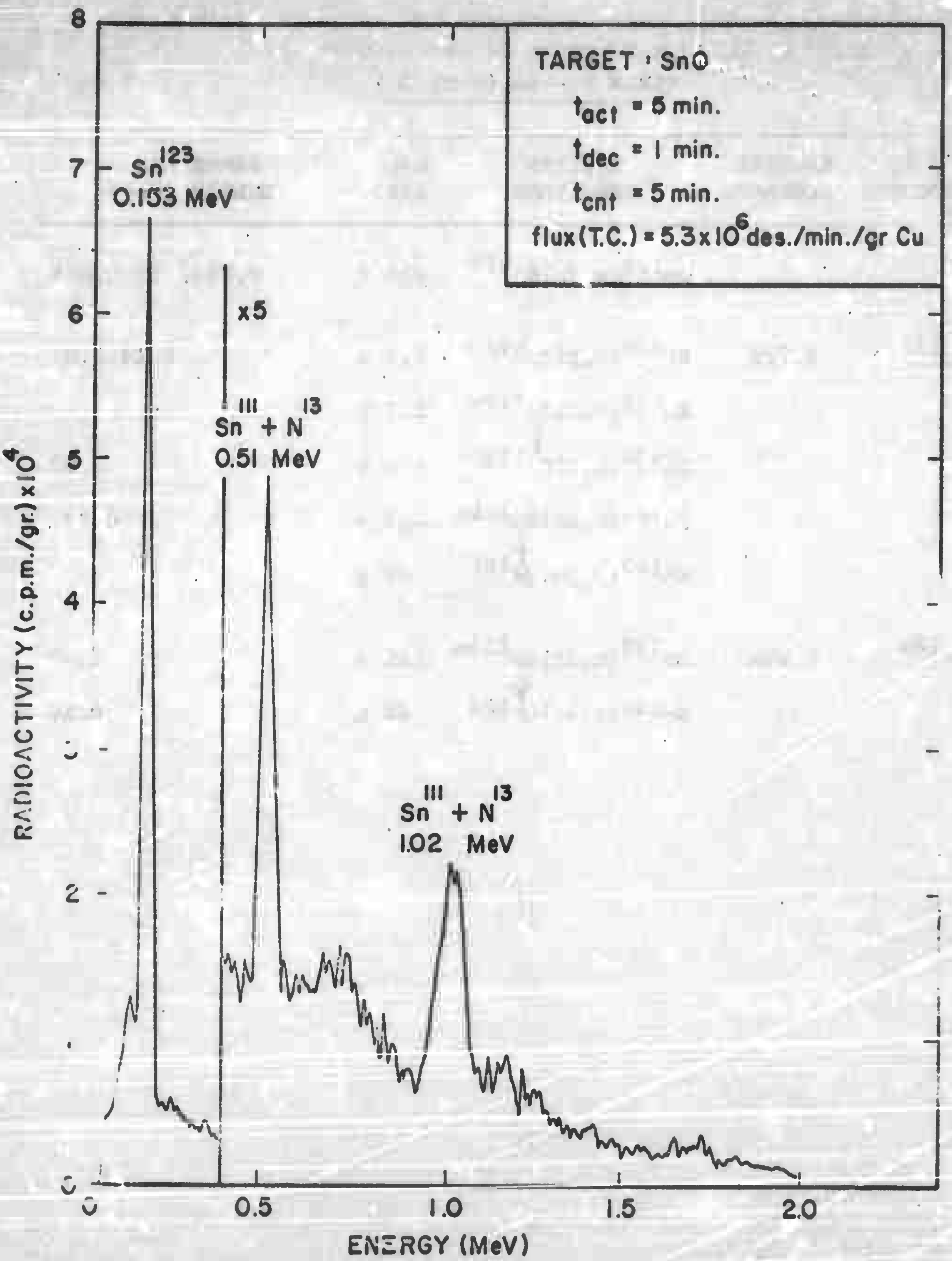

TARGET : SnO
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) = 5.3 x 10^6 des./min./gr Cu
Sn^{123}
0.153 MeV
x5
$Sn^{111} + N^{13}$
0.51 MeV
$Sn^{111} + N^{13}$
1.02 MeV
RADIOACTIVITY (c.p.m./gr.) x 10^4
ENERGY (MeV)
0
0.5
1.0
1.5
2.0
2
4
5
6
7
8

FIGURE I-Sn

TABLE II-Sn

PEAKS OBSERVED IN FIGURE I-Sn

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Sn	0.153	$Sn^{122}(n,\gamma)Sn^{123}$	40 m	
	0.511	$Sn^{112}(n,2n)Sn^{111}$	35 m	

NOTE: An irradiation shorter than five minutes, does not show photopeaks.

TABLE III-Sn

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/ mg/T_{cnt}	DETECTION LIMIT, mg
0.153	5 m	1 m	5 m	173	0.69

TABLE IV-Sn

POSSIBLE INTERFERING REACTIONS

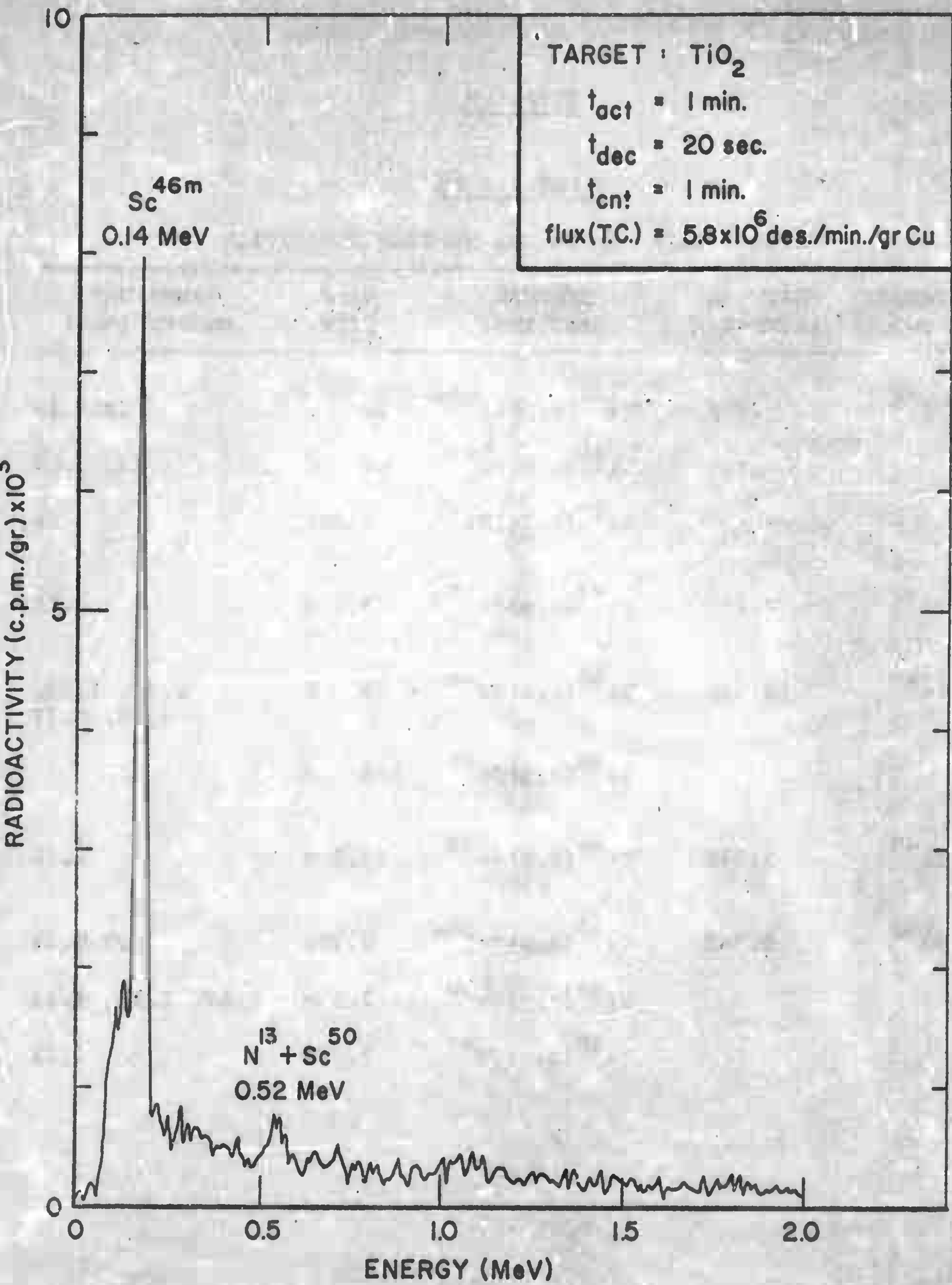
No detectable interferences could be derived for tin from any other element.

TITANIUM

TABLE I - Ti

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Ti^{46}	7.93%	$Ti^{46}(n,p)Sc^{46m}$	20 s	IT 0.14
		$Ti^{46}(n,p)Sc^{46}$	84 d	1.12, 0.89
		$Ti^{46}(n,2n)Ti^{45}$	3.08h	β+
Ti^{47}	7.28%	$Ti^{47}(n,p)Sc^{47}$	3.4 d	0.16
Ti^{48}	73.94%	$Ti^{48}(n,p)Sc^{48}$	44 h	1.31, 1.04, 0.99, 0.17
		$Ti^{48}(n,\alpha)Ca^{45}$	165 d	
Ti^{49}	5.51%	$Ti^{49}(n,p)Sc^{49}$	57.5 m	1.76
Ti^{50}	5.34%	$Ti^{50}(n,p)Sc^{50m}$	0.35s	IT 0.26
		$Ti^{50}(n,p)Sc^{50}$	1.8 m	0.52, 1.56, 1.12
		$Ti^{50}(n,\alpha)Ca^{47}$	4.7 d	1.31



TARGET : TiO_2
t_{act} = 1 min.
t_{dec} = 20 sec.
t_{cnt} = 1 min.
flux(T.C.) = 5.8×10^6 des./min./gr Cu
Sc^{46m}
0.14 MeV
$N^{13} + Sc^{50}$
0.52 MeV
RADIOACTIVITY (c.p.m./gr.) $\times 10^3$
ENERGY (MeV)
0
5
10
0
0.5
1.0
1.5
2.0

FIGURE I-Ti

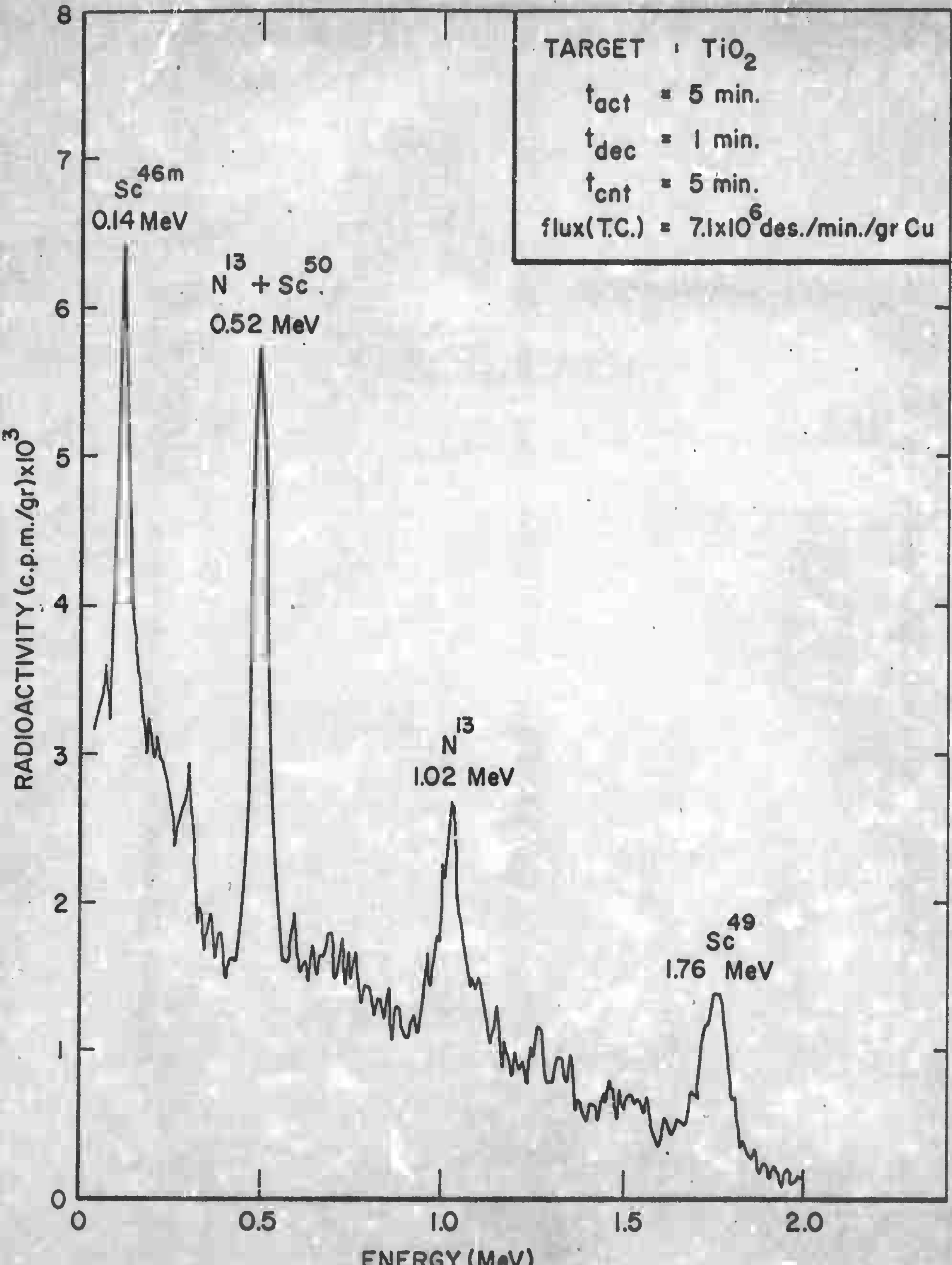

TARGET : TiO_2
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) = 7.1×10^6 des./min./gr Cu
Sc^{46m}
0.14 MeV
$N^{13} + Sc^{50}$
0.52 MeV
N^{13}
1.02 MeV
Sc^{49}
1.76 MeV
RADIOACTIVITY (c.p.m./gr) $\times 10^3$
ENERGY (MeV)
0
1
2
3
4
5
6
7
8
0.5
1.0
1.5
2.0

FIGURE II-Ti

TABLE II-Ti

PEAKS OBSERVED IN FIGURES I-Ti and II-Ti

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Ti	0.14	$Ti^{46}(n,p)Sc^{46m}$	20 s	
	0.52	$Ti^{50}(n,p)Sc^{50}$	1.8 m	
II-Ti	0.14	$Ti^{46}(n,p)Sc^{46m}$	20 s	
	0.52	$Ti^{50}(n,p)Sc^{50}$	1.8 m	
	1.76	$Ti^{49}(n,p)Sc^{49}$	57.5m	

TABLE III-Ti

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.14	1 m	20 s	1 m	17	2.5
0.14	5 m	1 m	5 m	7	18
0.52	5 m	1 m	5 m	9	18
1.76	5 m	1 m	5 m	8	7.1

TABLE IV-Ti

POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for titanium from any other element.

TUNGSTEN

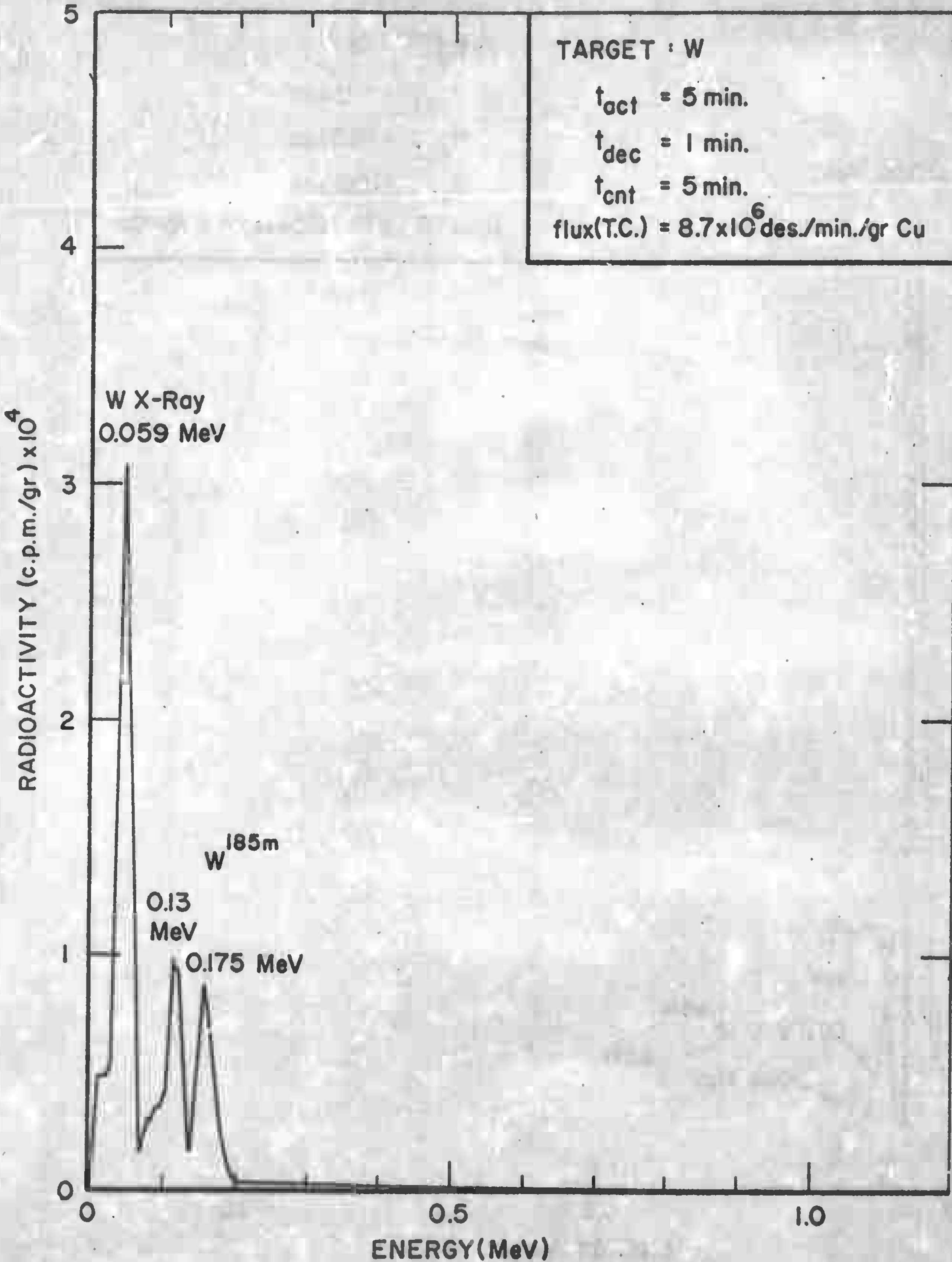
TABLE I - W

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
W^{180}	0.14%	$W^{180}(n,p)Ta^{180m}$	8.1 h	0.093, 0.102
		$W^{180}(n,2n)W^{179m}$	5 m	IT 0.222
		$W^{180}(n,2n)W^{179}$	30 m	0.031
		$W^{180}(n,n')W^{180m}$	0.005 s	0.10, IT 0.22, 0.5
W^{182}	26.41%	$W^{182}(n,p)Ta^{182m}$	16 m	0.15, 0.32, IT 0.18, 0.36
		$W^{182}(n,p)Ta^{182}$	115 d	0.10, 1.12, 1.22, 1.19
		$W^{182}(n,\alpha)Hf^{179m}$	19 s	0.217, IT 0.161
		$W^{182}(n,2n)W^{181m}$	14 μs	IT 0.37
		$W^{182}(n,2n)W^{181}$	130 d	0.15, 0.14
W^{183}	14.40%	$W^{183}(n,p)Ta^{183}$	5.0 d	0.246, 0.354, 0.108, 0.244, 0.041, 0.41
		$W^{183}(n,n')W^{183m}$	5.3 s	0.16, 0.21, IT 0.11
		$W^{183}(n,\alpha)Hf^{180}$	5.5 h	0.093, 0.44, IT 0.058, 0.50
W^{184}	30.64%	$W^{184}(n,p)Ta^{184}$	8.7 h	0.40, 0.111, 0.24, 0.91, 0.16, 1.44

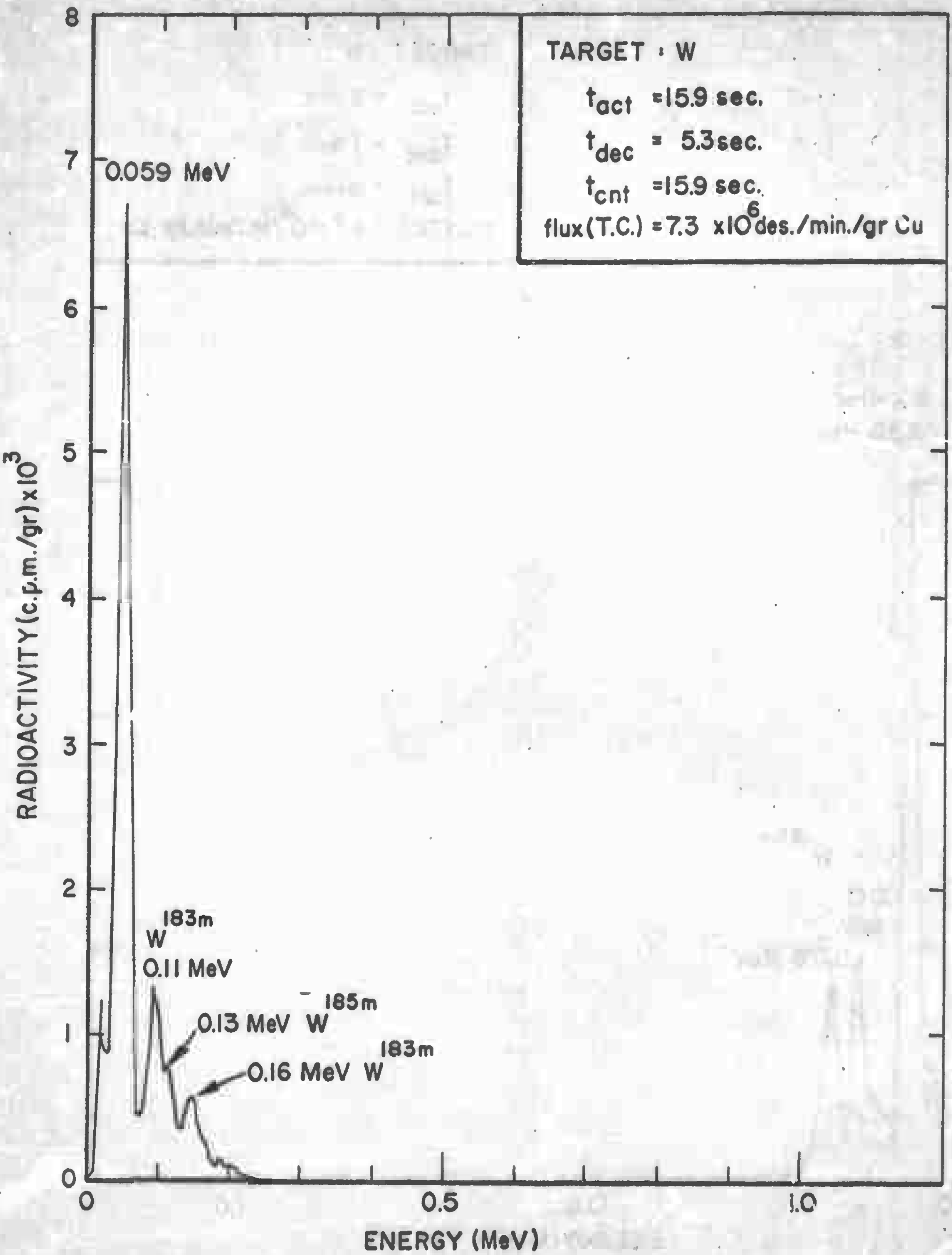
TABLE I - W (Cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
		$W^{184}(n,2n)W^{183m}$	5.3 s	0.16, 0.21, IT 0.11
		$W^{184}(n,\alpha)Hf^{181}$	45 d	0.48, 0.006, 0.70
W^{186}	28.41%	$W^{186}(n,p)Ta^{186}$	10 m	0.20, 0.73, 0.12, 0.11
		$W^{186}(n,2n)W^{185}$	1.7 m	0.075, 0.175
		$W^{186}(n,2n)W^{185m}$	74 d	0.125
		$W^{186}(n,\alpha)Hf^{183}$	1.1 h	



TARGET : W
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) = 8.7×10^6 des./min./gr Cu
W X-Ray
0.059 MeV
W^{185m}
0.13 MeV
0.175 MeV
RADIOACTIVITY (c.p.m./gr) $\times 10^4$
ENERGY(MeV)
0
1
2
3
4
5
0.5
1.0

FIGURE I-W



TARGET : W
t_{act} =15.9 sec.
t_{dec} = 5.3 sec.
t_{cnt} =15.9 sec.
flux(T.C.) = 7.3 x10^6 des./min./gr Cu
0.059 MeV
W^{183m}
0.11 MeV
0.13 MeV W^{185m}
0.16 MeV W^{183m}
RADIOACTIVITY (c.p.m./gr) x10^3
ENERGY (MeV)
0
1
2
3
4
5
6
7
8
0.5
1.0

FIGURE II-W

TABLE II-W

PEAKS OBSERVED IN FIGURES I AND II-W

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-W	0.059			W x-ray (1)
	0.13	$W^{186}(n,2n)W^{185m}$	1.7 m	(1)
	0.175	$W^{186}(n,2n)W^{185m}$	1.7 m	
II-W	0.059			W x-ray
	0.11	$W^{184}(n,2n)W^{183m}$	5.3 s	
	0.13	$W^{186}(n,2n)W^{185m}$	1.7 m	(1)
	0.16	$W^{183}(n,n')W^{183m}$	5.3 s	
		$W^{184}(n,2n)W^{183m}$	5.3 s	

(1) Refer, for explanation of photopeaks, to "Applied Gamma Ray Spectrometry" by C. E. Grouthamel.

TABLE III-W

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg) 1X	5X
0.059	15.9 s	5.3 s	15.9 s	29	3.0	1.3
0.11+0.13	15.9 s	5.3 s	15.9 s	2.5	15	8.0
0.16	15.9 s	5.3 s	15.9 s	2	27	13
0.059	5 m	1 m	5 m	38	4.2	
0.175	5 m	1 m	5 m	15	9.3	
0.13	5 m	1 m	5 m	12	15	

NOTE: Because of the very short half life of W^{183m}, five irradiation have been performed, and their spectra accumulated. The seventh column refers to the sensitivities obtained after five irradiations.

TABLE IV-W

POSSIBLE INTERFERING REACTIONS

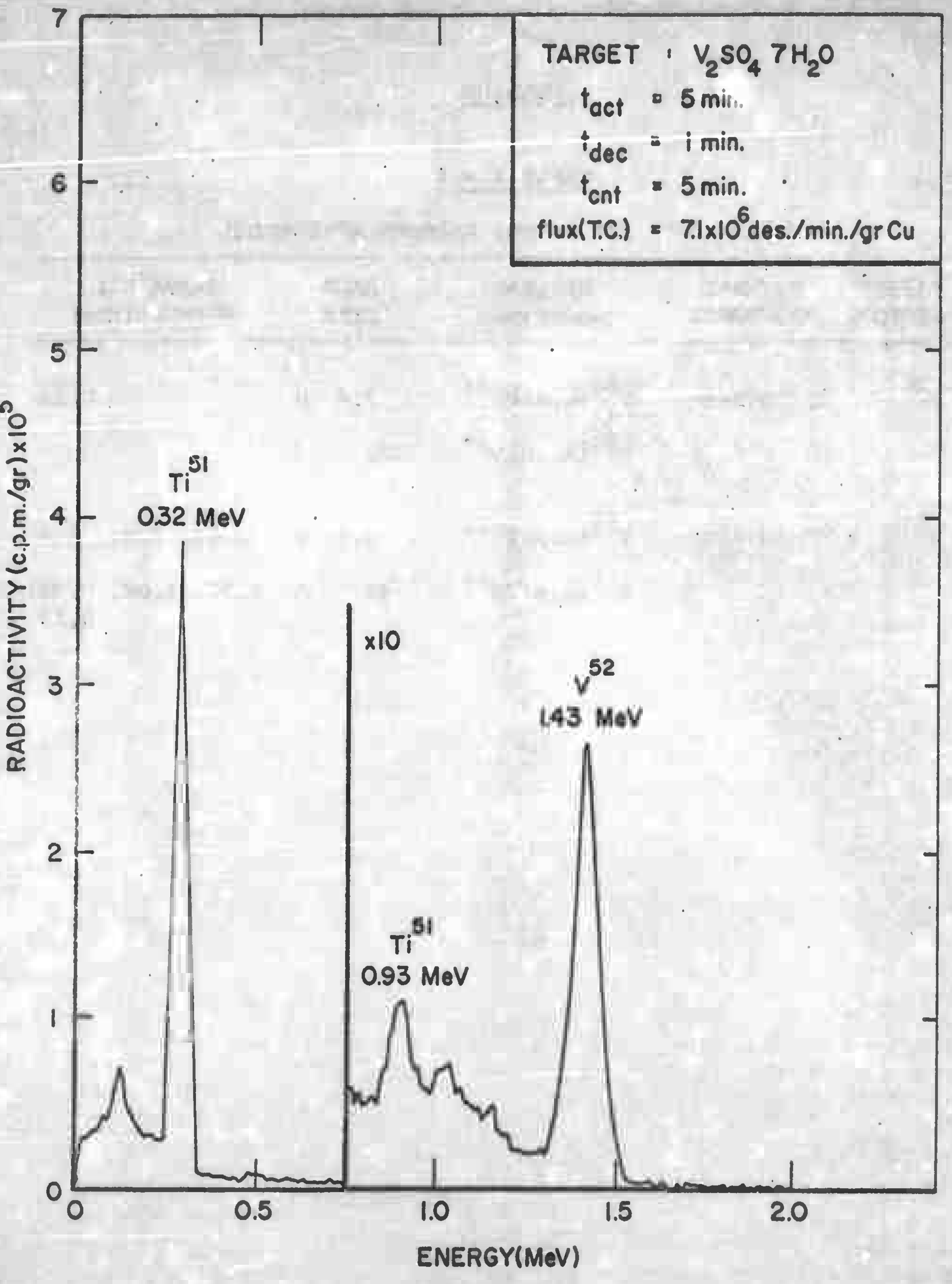
The possible reactions producing W^{183m} or W^{185m} from the element Rhenium or Osmium have not been investigated.

VANADIUM

TABLE I - V

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE		GAMMA RAY ENERGY (Mev)
V^{50}	0.24%	$V^{50}(n,\alpha)Sc^{47}$	3.4	d	0.16
		$V^{50}(n,2n)V^{49}$	330	d	
V^{51}	99.76%	$V^{51}(n,p)Ti^{51}$	5.8	m	0.32, 0.93, 0.61
		$V^{51}(n,\alpha)Sc^{48}$	44	h	1.31, 1.04, 0.99, 0.17



TARGET : V_2SO_4 $7H_2O$
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) = 7.1×10^6 des./min./gr Cu
RADIOACTIVITY (c.p.m./gr) x 10^5
Ti^{51}
0.32 MeV
x10
V^{52}
1.43 MeV
Ti^{51}
0.93 MeV
ENERGY(MeV)
0
1
2
3
4
5
6
7
0.5
1.0
1.5
2.0

FIGURE I-V

TABLE II-V

PEAKS OBSERVED IN FIGURE I-V

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-V	0.32	$V^{51}(n,p)Ti^{51}$	5.8 m	
	0.93	$V^{51}(n,p)Ti^{51}$	5.8 m	
	1.43	$V^{51}(n,\gamma)V^{52}$	3.77m	

TABLE III-V

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.32	5 m	1 m	5 m	1150	0.14
1.43	5 m	1 m	5 m	144	0.70

TABLE IV-V

POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
1.43	Chromium	$Cr^{52}(n,p)V^{52}$	
	Manganese	$Mn^{55}(n,\alpha)V^{52}$	

YTTRIUM

TABLE I - Y

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Y^{89}	100%	$Y^{89}(n,p)Sr^{89}$	50.4 d	
		$Y^{89}(n,\alpha)Rb^{86m}$	1 m	IT 0.56
		$Y^{89}(n,\alpha)Rb^{86}$	18.7 d	1.08
		$Y^{89}(n,2n)Y^{88m}$	300 μs	IT 0.39
		$Y^{89}(n,2n)Y^{88m}$	0.014 s	IT 0.24
		$Y^{89}(n,2n)Y^{88}$	108 d	1.83, 0.90, β+
		$Y^{89}(n,n')Y^{89m}$	16 s	IT 0.91

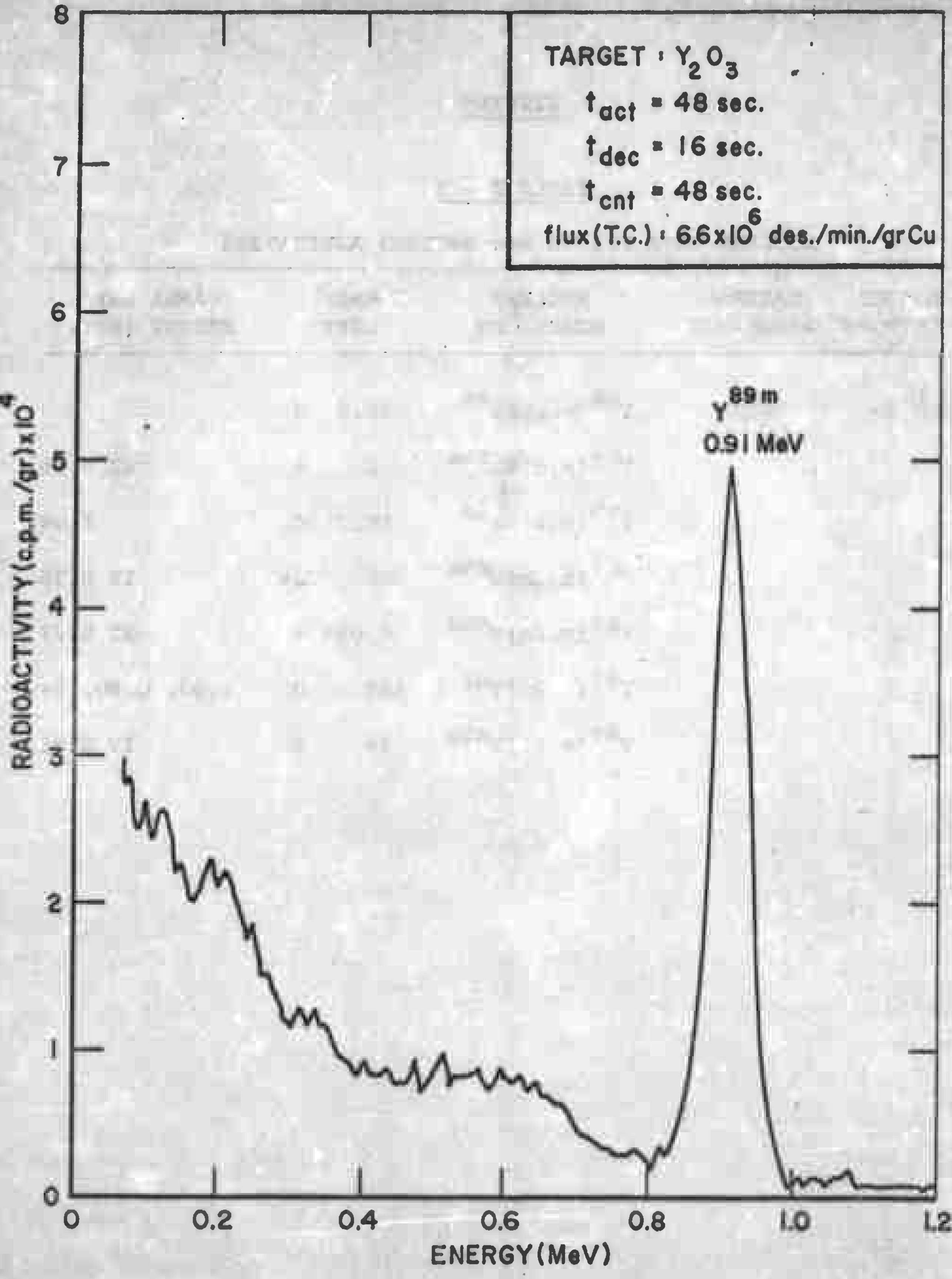

TARGET : Y_2O_3
t_{act} = 48 sec.
t_{dec} = 16 sec.
t_{cnt} = 48 sec.
flux (T.C.) : 6.6×10^6 des./min./gr Cu
Y^{89m}
0.91 MeV
RADIOACTIVITY (c.p.m./gr) $\times 10^4$
ENERGY (MeV)
0
1
2
3
4
5
6
7
8
0
0.2
0.4
0.6
0.8
1.0
1.2

FIGURE I-Y

TABLE II-Y

PEAKS OBSERVED IN FIGURE I-Y

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Y	0.91	$Y^{89}(n,n')Y^{89m}$	16 s	

NOTE: After a 3 minute irradiation time of Yttrium, the activity due to Rb^{86m} could not be positively identified because of the rather high activity at 0.51 Mev due to the vial.

TABLE III-Y

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT (mg)
0.91	48 s	16 s	48 s	314	0.58

TABLE IV-Y

POSSIBLE INTERFERING REACTIONS

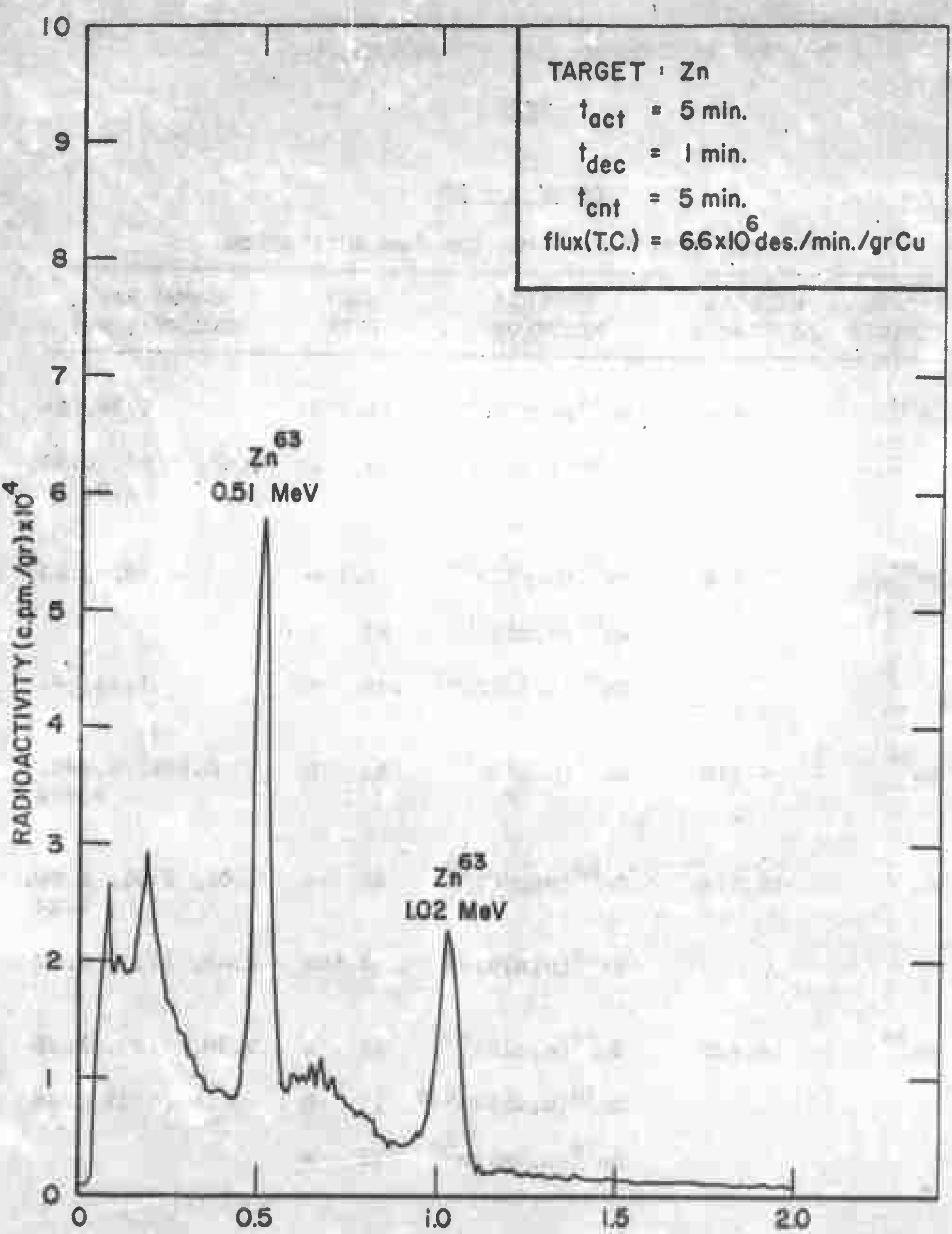
GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.91	Zirconium	$Zr^{90}(n,n'p)Y^{89m}$	
	Niobium	$Nb^{93}(n,n'\alpha)Y^{89m}$	

ZINC

TABLE I - Zn

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Zn^{64}	48.89%	$Zn^{64}(n,p)Cu^{64}$	12.9 h	1.34, β+
		$Zn^{64}(n,2n)Zn^{63}$	38 m	0.67, 0.97, 0.81, 2.9, β+
Zn^{66}	27.81%	$Zn^{66}(n,p)Cu^{66}$	5.1 m	1.04, 0.83
		$Zn^{66}(n,\alpha)Ni^{63}$	92 y	
		$Zn^{66}(n,2n)Zn^{65}$	245 d	1.12, β+
Zn^{67}	4.11%	$Zn^{67}(n,p)Cu^{67}$	61 h	0.182, 0.090, 0.092
Zn^{68}	18.57%	$Zn^{68}(n,p)Cu^{68}$	30 s	1.08, 0.81, 1.88, 1.24
		$Zn^{68}(n,\alpha)Ni^{65}$	2.56h	1.49, 1.12, 0.37
Zn^{70}	0.62%	$Zn^{70}(n,\alpha)Ni^{67}$	50 s	0.90, 0.89, 1.26
		$Zn^{70}(n,2n)Zn^{69m}$	14 h	IT 0.44
		$Zn^{70}(n,2n)Zn^{69}$	55 m	



TARGET : Zn
t_{act} = 5 min.
t_{dec} = 1 min.
t_{cnt} = 5 min.
flux(T.C.) = 6.6×10^6 des./min./gr Cu
Zn^{63} 0.51 MeV
Zn^{63} 1.02 MeV
RADIOACTIVITY (c.pm./gr) x 10^4
ENERGY (MeV)
0
0.5
1.0
1.5
2.0
1
2
3
4
5
6
7
8
9
10

FIGURE I-Zn

TABLE II-Zn

PEAKS OBSERVED IN FIGURE I-Zn

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Zn	0.51	$Zn^{64}(n,2n)Zn^{63}$	38 m	
	1.02	$Zn^{64}(n,2n)Zn^{63}$	38 m	0.51 Mev coincidence sum peak

TABLE III-Zn

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.51	5 m	1 m	5 m	212	0.77

TABLE IV-Zn

POSSIBLE INTERFERING REACTIONS

No detectable interference could be noted for zinc from any other element.

For other positron emitting radioisotopes besides Zn^{63}, see Section I, Appendix II.

ZIRCONIUM

TABLE I - Zr

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Zr^{90}	51.46%	$Zr^{90}(n,p)Y^{90m}$	3.2 h	0.20, IT 0.48
		$Zr^{90}(n,p)Y^{90}$	64.2 h	1.75
		$Zr^{90}(n,\alpha)Sr^{87m}$	2.8 h	IT 0.39
		$Zr^{90}(n,2n)Zr^{89m}$	4.2 m	1.5, β+, IT 0.59
		$Zr^{90}(n,2n)Zr^{89}$	78.4 h	0.91, 1.7, β+
		$Zr^{90}(n,n')Zr^{90m}$	0.8 s	2.18, IT 2.32, 0.14
Zr^{91}	11.23%	$Zr^{91}(n,p)Y^{91m}$	50 m	IT 0.55
		$Zr^{91}(n,p)Y^{91}$	59 d	1.21
		$Zr^{91}(n,2n)Zr^{90m}$	0.8 s	2.18, IT 2.32, 0.14
Zr^{92}	17.11%	$Zr^{92}(n,p)Y^{92}$	3.53h	0.932, 1.39, 0.56, 0.448, 2.4
		$Zr^{92}(n,\alpha)Sr^{89}$	50.4 d	
Zr^{94}	17.40%	$Zr^{94}(n,p)Y^{94}$	20 m	0.92, 0.56, 1.13, 1.65, 3.5
		$Zr^{94}(n,\alpha)Sr^{91}$	9.7 h	0.55, 0.65, 1.41
		$Zr^{94}(n,2n)Zr^{93}$	9.5×10^5y	0.029

TABLE I - Zr (Cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Zr^{96}	2.80%	$Zr^{96}(n,p)Y^{96}$	2.3 m	0.7, 1.0
		$Zr^{96}(n,\alpha)Sr^{93}$	8.3 m	0.6, 0.8, 0.31, 2.1
		$Zr^{96}(n,2n)Zr^{95}$	65 d	0.72, 0.76, 0.23, 0.77

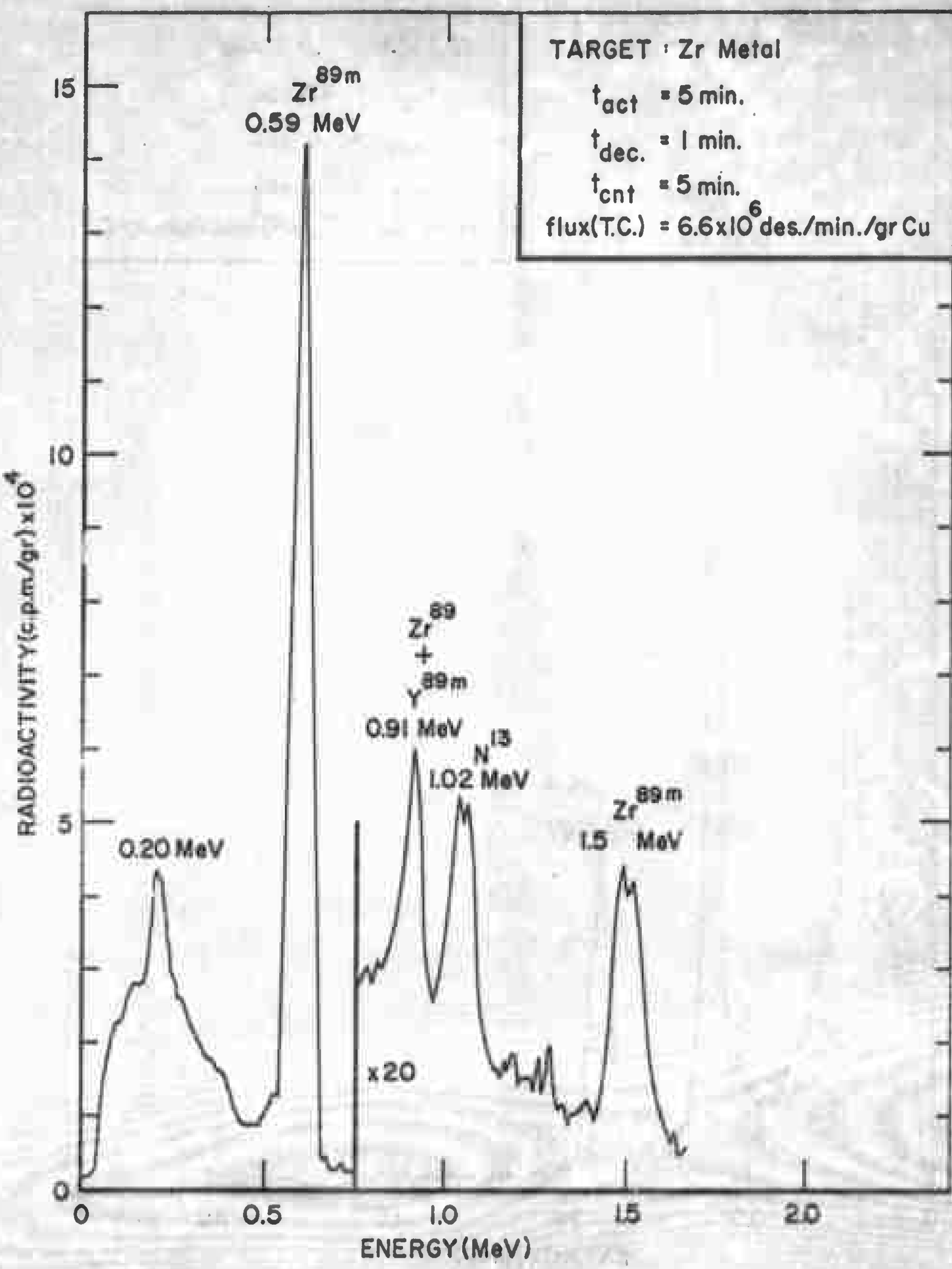

TARGET : Zr Metal
t act = 5 min.
t dec. = 1 min.
t cnt = 5 min.
flux(T.C.) = 6.6x10 6 des./min./gr Cu
Zr 89m
0.59 MeV
0.20 MeV
Zr 89
+
Y 89m
0.91 MeV
N 13
1.02 MeV
Zr 89m
1.5 MeV
x20
RADIOACTIVITY(c.p.m./gr) x 10 4
ENERGY(MeV)
0
5
10
15
0.5
1.0
1.5
2.0

FIGURE I-Zr

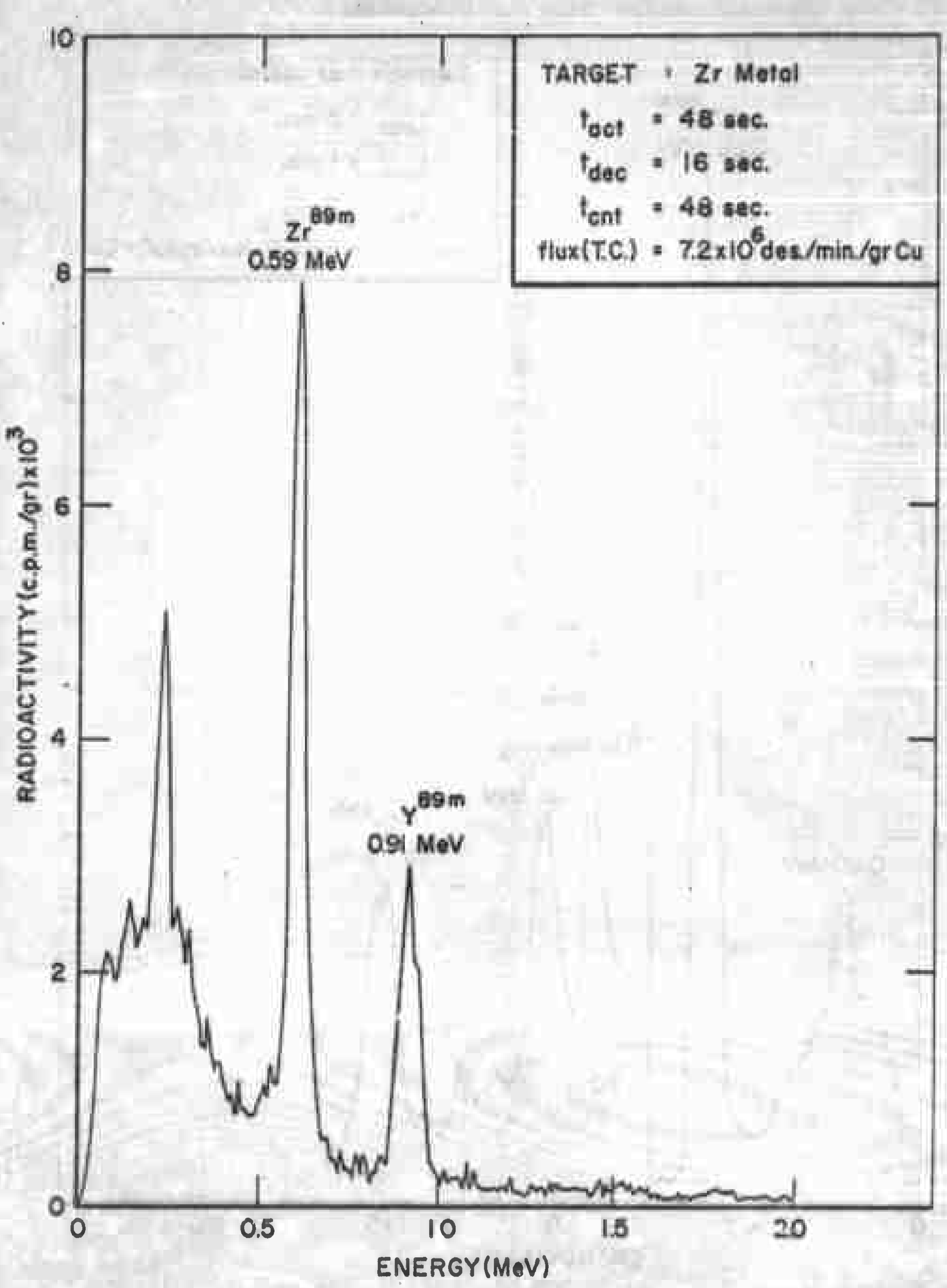

TARGET : Zr Metal
t_{act} = 48 sec.
t_{dec} = 16 sec.
t_{cnt} = 48 sec.
flux(T.C.) = 7.2×10^6 des./min./gr Cu
Zr^{89m}
0.59 MeV
Y^{89m}
0.91 MeV
RADIOACTIVITY (c.p.m./gr) $\times10^3$
ENERGY (MeV)
0
2
4
6
8
10
0
0.5
1.0
1.5
2.0

FIGURE II-Zr

TABLE II-Zr

PEAKS OBSERVED IN FIGURE I-Zr and II-Zr

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Zr	0.20	$Zr^{90}(n,p)Y^{90m}$	3.2 h	Major activity due to backscattering
	0.59	$Zr^{90}(n,2n)Zr^{89m}$	4.2 m	
	0.91	$Zr^{90}(n,n'p)Y^{89m}$	16 s	
		$Zr^{90}(n,2n)Zr^{89}$	78.4 h	
	1.5	$Zr^{90}(n,2n)Zr^{89m}$	4.2 m	
II-Zr	0.59	$Zr^{90}(n,2n)Zr^{89m}$	4.2 m	
	0.91	$Zr^{90}(n,n'p)Y^{89m}$	16 s	

TABLE III-Zr

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T_{act}	T_{dec}	T_{cnt}	COUNTS/mg/T_{cnt}	DETECTION LIMIT(mg)
0.91	48 s	16 s	48 s	15	2.9
0.59	48 s	16 s	48 s	32	1.5
0.59	5 m	1 m	5 m	645	0.25

NOTE: Zr^{90m} detectable for 2.4 sec irradiation, 0.8 sec decay and 2.4 sec counting time. The activity is however very low.

TABLE IV-Zr

POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.91	Yttrium	$Y^{89}(n,n')Y^{89m}$	
	Niobium	$Nb^{93}(n,n'\alpha)Y^{89m}$	

APPENDIX I

The Texas Convention On The Measurement Of 14 Mev Neutron Fluxes From Accelerators

INTRODUCTION

There exists at present no generally accepted method for determining effective fluxes of 14 Mev neutron energies from generators using the $T(d,n)He^4$ reaction which can be used for fast neutron activation analysis. In order to facilitate inter-laboratory comparisons of fluxes and establish a common bases for the determination of fast neutron fluxes quoted in the Activation Analysis literature the following convention has been adopted.

SPECIFICATION

The effective fluxes for sample activations are to be measured by exposing high purity (99.9%) copper discs of 0.25mm thickness and 1 cm and/or 2.5 cm diameter for 1 minute to the neutron flux to be measured. After a minimum cooling time of 1 minute, to permit sample transfer and decay of interfering N^{16} activity, the positron annihilation radiation emitted by the disc is counted and the disintegration rate of the Cu^{62} activity determined for the time of the end of the activation. The flux is then given in disintegrations/minute/gram copper and the size of the disc is stated.

APPENDIX II

Counting Recommendations For The Measurement Of 14 Mev Neutron Flux From Accelerators

R. L. Heath
National Reactor Testing Station
Idaho Falls, Idaho

In the interest of providing a uniform method for assay of copper flux monitors, the following procedure is suggested to provide a standard method of measurement and data analysis which can readily be produced by most experimenters. It is proposed that the activated foils be assayed by quantitative scintillation spectrometry to obtain the disintegration rate for the 9.9 min Cu^{62} activity induced in the foil by the n,2n reaction. If appropriate corrections are applied for irradiation time, decay following irradiation, and the various experimental parameters of the counting arrangement, the result will provide a number which will be proportional to neutron flux.

It is suggested that the copper discs (either 1 or 2.5cm diameter by 0.25 mm thickness) be mounted between two discs of polystyrene or lucite to insure that all positrons emitted in the decay are annihilated in the immediate vicinity of the disc source. The plastic discs should be 3/8" thick (0.95 cm) by either 3 cm or 4.5 cm diameter, depending on which size

copper disc is to be used. The resulting sandwich will provide approximately 1 gram/cm^2 of plastic on all sides of the copper disc. The source sandwich is to be mounted on the central axis of a 3" diameter by 3" cylindrical NaI detector with the copper disc at a distance of 3 cm from the top surface of the NaI crystal. To accomplish this it will be necessary to determine the distance from the top surface of the detector to the outside surface of the detector can. In present commercial detectors this distance may vary from 2 to 4 mm.

With the source mounted in this manner a pulse-height spectrum of the gamma radiation emitted in the decay of Cu^{62} should be obtained. It is assumed that this measurement will be made on a modern multi-channel analyzer incorporating an automatic live-time correction circuit. For the purpose of the decay correction, the mid-point of the counting interval will be used. It will be necessary to consider the difference between real clock time and live time in making the decay correction. To obtain a value which closely approximates the disintegration rate of the sample, the photopeak method outlined in the Gamma-Ray Spectrum Catalogue[5] will be used. An estimate of the contribution to the 0.511 Mev photopeak from the bremsstrahlung should be made. The "photopeak area" is

then obtained by summing the counts in all peak channels. For this purpose the photopeak is defined as a symmetrical shape with the low-energy side of the peak the mirror image of the shape on the high-energy side. The disintegration rate of the source will then be given by the following relationship:

$$N_o = \frac{N_p}{(P)(\epsilon)(A_q)}$$

where N_p is the photopeak area in counts/min, ϵ is the calculated efficiency for the source detector geometry being used, A is an absorption correction for the plastic absorber and detector can, q is the branching ratio for the 0.511 Mev annihilation radiation, and P is the experimental photopeak efficiency for these conditions. To simplify this procedure the quantity $(1/P)(\epsilon)(A_q)$ has been calculated for this experiment. To obtain the disintegration rate for the sample at the time of measurement one need only to multiply this factor by the photopeak area. Although some simplifying assumptions have been made in this calculation, the result should be accurate to within $\pm$ 5%.

	1 cm diameter disc	5 cm diameter disc
$(1/P)(\epsilon)(A_q)$	8.591	8.703

APPENDIX III

Elements Producing Positron Emitters

Table II lists the elements which, after irradiation with 14 Mev neutrons, produce a 0.51 Mev photopeak as a major peak in the spectrum. This photopeak is due to the annihilation of the positrons.

The radioisotopes producing, in a 5-minute irradiation time, a very low activity are not listed (example Cu^{64} T = 12.8 hr).

Table II

Elements Producing Positron Emitters

Element	Nuclear Reactions	Half Life
Phosphorus	$P^{31}(n,2n)P^{30}$	2.5 m
Praseodymium	$Pr^{141}(n,2n)Pr^{140}$	3.4 m
Bromine	$Br^{79}(n,2n)Br^{78}$	6.5 m
Potassium	$K^{39}(n,2n)K^{38}$	7.7 m
Iron	$Fe^{54}(n,2n)Fe^{53}$	8.5 m
Samarium	$Sm^{144}(n,2n)Sm^{143}$	9.0 m
Nitrogen	$N^{14}(n,2n)N^{13}$	9.96 m
Copper	$Cu^{63}(n,2n)Cu^{62}$	9.9 m
Molybdenum	$Mo^{92}(n,2n)Mo^{91}$	15,5 m
Antimony	$Sb^{121}(n,2n)Sb^{120}$	15.9 m
Silver	$Ag^{107}(n,2n)Ag^{106}$	24 m
Chlorine	$Cl^{35}(n,2n)Cl^{34}$	32.0 m
Zinc	$Zn^{64}(n,2n)Zn^{63}$	38.0 m
Chromium	$Cr^{50}(n,2n)Cr^{49}$	42 m
Gallium	$Ga^{69}(n,2n)Ga^{68}$	68 m
Fluorine	$F^{19}(n,2n)F^{18}$	110 m
Palladium	$Pd^{102}(n,2n)Pd^{101}$	8.5 hr
Nickel	$Ni^{58}(n,2n)Ni^{57}$	36 hr

APPENDIX IV

Elements Emitting High Energy Gamma Rays

Oxygen, fluorine and boron are the only elements which produce after 14 Mev neutron activation, radioisotopes emitting gamma photons with energies greater than 4.5 Mev.

For this reason it is possible to detect the produced radioisotopes using a single channel analyzer with a lower discrimination level at 4.5 Mev.

In the above described conditions the following experimental results were obtained.

	Oxygen	Fluorine	Boron
Nuclear reaction	$O^{16}(n,p)N^{16}$	$F^{19}(n,\alpha)N^{16}$	$B^{11}(n,p)Be^{11}$
Half life	7.35 sec	7.35 sec	13.6 sec
Gamma ray energy (Mev)	6.13, 7.12	6.13, 7.12	2.12, 6.8, 4.6, 8.0
Activation time	22 sec	22 sec	40.8 sec
Decay time	7.3 sec	7.3 sec	13.6 sec
Count time	22 sec	22 sec	40.8 sec
Counts/mg/T_{cnt}	91	38	29

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